DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

DEVELOPMENT AND TESTS OF A RADIOACTIVE SEDIMENT DENSITY PROBE

TECHNICAL MEMORANDUM NO. 121

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SEPTEMBER 1960

FOREWORD

In connection with its responsibilities for maintaining navigable waterways and flood control reservoirs, the Corps of Engineers has a need for determining quickly and economically the amounts of solid materials in sedimentary deposits. A project for development of an in-place sediment density gage was funded under the Civil Works Investigation Program of the Office, Chief of Engineers; this project (CW 176) was assigned to the staff of the Beach Erosion Board in July 1956.

During the later stages of making the decisions relative to the possible and desired accuracy and characteristics of the probe, the staff of the Beach Erosion Board requested the assistance of the staff of the Ohio River Division Laboratories of the U. S. Army Corps of Engineers in negotiating toward the selection of a contractor to undertake this development and in administering the contract. Mr. Paul F. Carlton was assigned by the Laboratories to assist the Board's staff in this matter and worked closely with the staff until delivery of the probe by the contractor in January 1958. Technical Operations, Inc. of Burlington, Massachusetts was selected as contractor to develop the probe. Dr. Marvin G. Schorr was the Project Supervisor for the contractor and Dr. I. L. Kofsky, the Project Scientist. The contractor investigated numerous possibilities of isotopes, probe sizes and geometric arrangements, detector, and preamplifier designs. The detailed analysis by the contractor is contained in the report, "Final Report on Development of Sediment Density Probe," by Dr. I. L. Kofsky, dated March 1958 (Report No. TOI 58-5). Copies of this final report are available on loan from the library of the Beach Erosion Board. The present report gives the details of laboratory and field tests of the probe, as well as a summary of the development work.

This report was prepared by Joseph M. Caldwell, Chief of the Research Division of the Beach Erosion Board. Several members of the staff of the Beach Erosion Board assisted the author in this development. Specific credit should be given to Mr. Leo C. Williams and Mr. Cyrus M. Hare, both Electronic Engineers, for their work in calibrating the gage, to Mr. Culbertson W. Ross, Hydraulic Engineer, for assisting in the calculation of mass absorption coefficients, to Mr. Norman E. Taney, Geologist, for assistance in determining the physical and chemical characteristics of the materials used in the calibration tests, and to Mr. Francis W. Kellum, Electronic Technician who trained field personnel and assisted in nearly all field tests to date. At the time of completion of the report Major General W. K. Wilson, Jr. was President of the Board; R. O. Eaton was Chief Technical Advisor. The report was edited for publication by A. C. Rayner, Chief of the Project Development Division.

Views and conclusions expressed in this report are not necessarily those of the Beach Erosion Board.

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By

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INTRODUCTION

The shoaling of navigable waterways and the filling of reservoirs by sedimentary material result in costly maintenance in the first case and loss of storage capacity in the second case. In attempting to overcome the problems presented by these deposits, the engineer is handicapped by the lack of a suitable means for determining, quickly and economically, the actual amount of solid material in the shoal.

The shoals may be very thin fluid mixtures with specific gravities of less than 1.1 or may be relatively dense mixtures with specific gravities of 1.5 or more. In either case, the leadline and the echo sounder can at best give only a very qualitative estimate of the density of the shoal material under observation. The mechanical sampling devices currently used to obtain undisturbed samples are rather expensive to operate and the analysis of the resulting samples is rather tedious and expensive; also, there is some doubt that many of the samplers in use obtain a truly representative sample of the shoal material.

In view of the desirability of improving the methods of studying underwater deposits, the possibilities of developing a suitable device were reviewed. This review indicated that no device along the lines contemplated had been developed, but that a practical device could probably be developed at a reasonable cost. The purpose of the approved project was to develop, for field use, a density probe utilizing nuclear radiation which would measure the density, in place, of unconsolidated marine sediments of the type normally encountered in navigation channels and reservoirs.

DESIGN CRITERIA

Contemplated Operating Conditions. The initial step under the project was the establishment with some definitude the field conditions under which the probe would be expected to function, the degree of accuracy necessary, and the method of actually carrying out the development. The field conditions under which the probe would be expected to function were discussed with engineers experienced in navigation channel maintenance and in reservoir operations. Also, the literature bearing on this subject was studied. From these discussions and studies a rough classification of shoal deposits into three types was made as follows:

	Thin Shoal	Soft Shoal	Hard Shoal
Specific gravity of mixture	1.00 to 1.03	1.02 to 1.35	1.3 to 2.2
Weight of mixture (pounds per cu. ft.)	62.4 to 64.4	64 to 84	81 to 138
Pounds of soil solids per cu. ft. of mixture	0 to 2	1.5 to 35	30 to 120

These ranges are somewhat arbitrary and are purposely set up to show some overlapping. The figures refer to shoals in fresh water; the figures would, of course, be slightly different for shoals in salt water.

The concensus of the engineers with whom the matter was discussed was that the shoals of greatest interest were those lying in the classification of "soft" shoals as indicated above. The "thin" shoals are, almost invariably, very liquid in character and offer little resistance to navigation; they are therefore of secondary interest. The "hard" shoals would seldom be found in an established navigation channel, except as sand shoals, as the silt and clays deposits would generally not be permitted to solidify to this degree before being dredged. As a result, it was decided to concentrate on the development of a suitable probe to cover shoals with specific gravities between 1.02 and 1.35.

The decision to develop a probe for "soft" shoals simplified the design. For one thing, an attempt to work in the thin shoal range would have required a very high degree of discrimination to detect significant changes between specific gravities over the 1.00 to 1.03 range. For another thing, an attempt to work in the hard shoal range would have necessitated the development of a very rugged probe which could be hammered down into the shoal.

The discussion referred to above led also to a decision to consider 75 feet as the maximum depth in which the probe would be expected to work and to require that the probe be remote indicating. This latter requirement was designed to permit the density of a shoal to be measured without withdrawing the probe; instead, the probe would detect the density and furnish the signal to an indicator or recorder on the survey boat at the surface. Thus, the stratification of a shoal could be measured by taking a series of readings while pushing the probe farther and farther into the shoal.

Further requirements were decided upon, some structural and some electrical. These requirements are summarized in Appendix A, which is taken from the contract under which the probe was developed.

Desired Accuracy. The potential accuracy of the probe could not be completely determined before its development; however, it appeared desirable to set at least a minimum accuracy goal. As previously indicated the anticipated sediment content range for the probe was from 1.5 to 35 pounds of soil solids content per cubic foot of mixture. A determination to within one pound of the soil solids content over this range was decided upon as a reasonable requirement. This would, in effect, require the detecting and indicating components of the probe, acting together, to give a reliable determination to somewhere within 1.2 to 1.5 percent of the actual mass density of the shoal mixture.

As several factors not susceptible to prior evaluation were recognized as affecting the accuracy of the probe, the development contractor was not required to attain this degree of accuracy, but to utilize "his best effort to meet or exceed" these minimum operating characteristics.

PROBE DEVELOPMENT

In carrying forward the development, the contractor made an analytical study of the available possibilities. These analytical studies, which included laboratory tests, were made to enable a decision to be made as to, among other things, the following:

a. The identity and quantity of the isotope to be used.

b. The method of detecting the radioactivity passing through the soil mass, i.e. whether by Geiger-Muller tubes or by scintillation counters.

c. The use of a reflection or an absorption technique, i.e. whether or not the single-pointed probe or a double-pointed probe (one point with the isotope and one with the detector) would be used.

d. The materials to be used in the probe and the physical dimensions and positions of the component parts of the probe.

The contract did not include the development of a scaler to totalize the number of impulses detected by the probe. A scaler suitable for this purpose had already been developed for the Ohio River Division Laboratories of the Corps of Engineers by the Nuclear-Chicago Corporation in connection with soil moisture studies. The contractor for the probe was required to develop a signal from the probe which would operate this previously developed scaler. This instrument, the Model 2800 Portable Scaler, has the following characteristics:

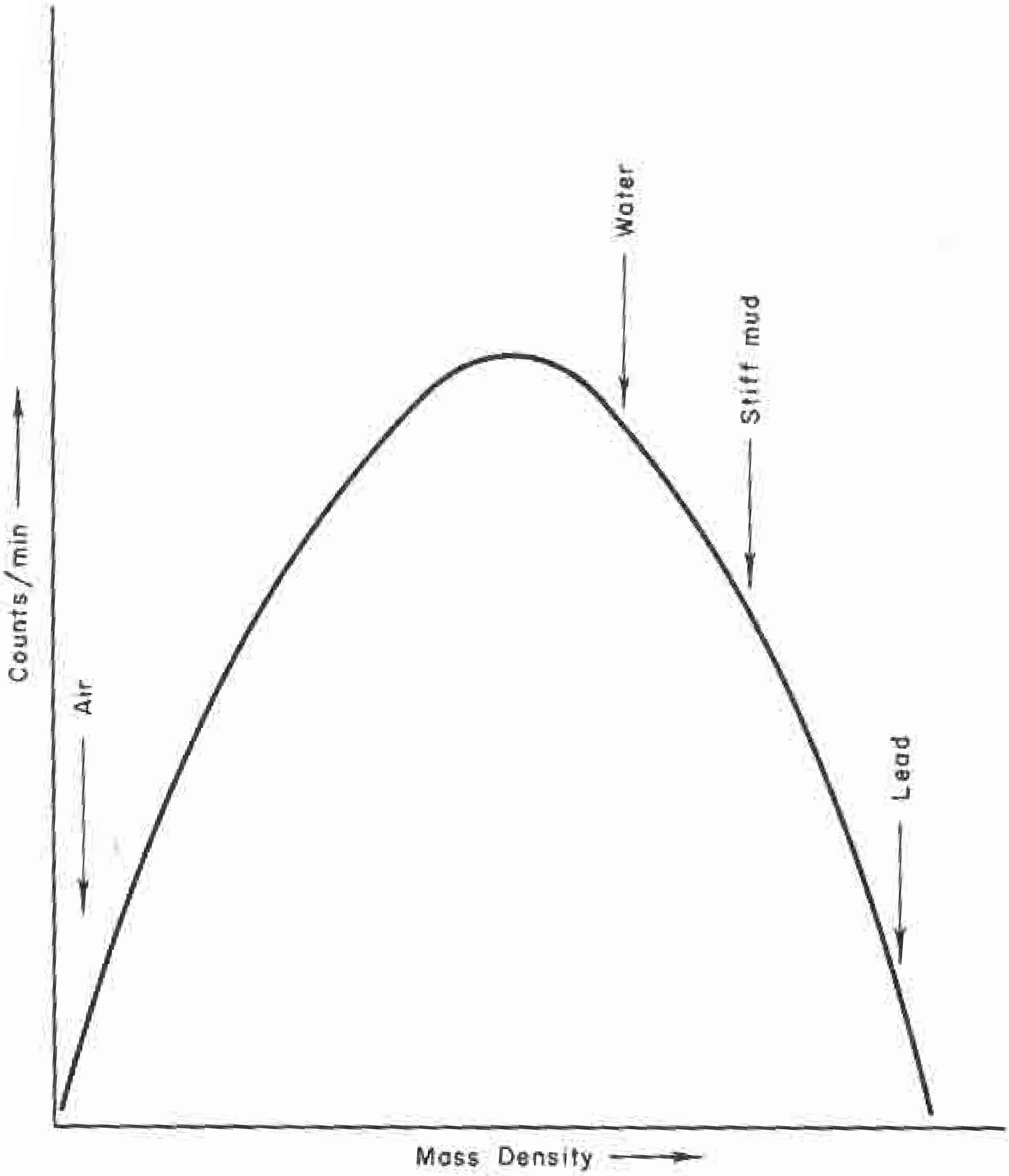


FIGURE I. THEORETICAL RESPONSE CURVE OF DENSITY PROBE

Totalizes to 1,000,000 counts

Airplane-type wet-cell batteries not subject to spillage or leakage

Operates from the internal batteries or from external 6-volt D. C. or 110-volt A. C. source

Supplies 1075-volt D. C. voltage for charging the counter tubes in the probe

The scaler indicates visually the total impulses counted over a measured time interval. The operator records the count from the visual counter tubes.

Arrangement of Probe. The contractor's study led to the decision to develop a single-pointed probe rather than a double-pointed one. Under this arrangement, the radioactive source would be placed near the tip of the probe with the detectors some 7 inches above it in the barrel of the probe. The intervening 7 inches would be filled with a lead plug to shield the detector from the direct rays of the radioactive source.

Thus the rays leaving the source first would enter the medium surrounding the probe where some would be absorbed and some reflected. Part of the reflected rays would find their way to the detectors above the lead plug. The greater the reflecting properties of the medium, the greater would tend to be the number of rays reflected toward the detectors. Conversely, the greater the absorbing properties of the medium, the fewer the rays that actually would reach the detectors. Thus, air would tend to give a low count because very few rays would be reflected toward the detectors and lead would give a very low count, most of the rays - even when reflected - being absorbed before they would reach the detectors. Actually, materials intermediate in property between air and lead could be expected to give a greater count than either of the two. This relationship is illustrated on Figure 1 which shows that for a given arrangement some particular material would turn the most rays to the detectors.

It can also be seen from Figure 1 that it appears possible to develop a probe which would work on the rising side of the curve, i.e. mud at 1.05 specific gravity would give less count than mud at 1.40 specific gravity. On the other hand, it appears possible to work on the descending side of the curve where the count would decrease as the density increased. The contractor decided to work on the descending side of the curve and developed the probe accordingly. Thus, in the probe as constructed a higher count is obtained in pure water than in mud.

Choice of Radioactive Source. The density of the shoal materials to be studied with the probe quickly indicated that a gamma-ray source of radioactivity would be necessary. Alpha-ray and beta-ray sources would be unsuitable due to their low penetrating power, the alpha rays being stopped almost completely by a sheet of paper and the beta rays by 1 or 2 centimeters of water. Gamma rays, on the other hand, can penetrate from one to several feet of water depending on the energy of the rays.

The source selection was thus influenced by the desire to keep the radioactivity low to minimize danger to personnel handling the probe, but high enough to insure sufficient penetration to give a significant count by the scaler. Radioactivity is not an even flow of energy but rather comes in bursts of high activity followed by periods of low activity. It has been determined that the statistical probable error varies as the square root of the actual count. The importance of this concept is shown by the following tabulation:

Total Count	Probable Error in Count	Probable Error in % of Total Count
10	3.17	31.7
100	10.	10.0
1,000	31.7	3.17
10,000	100	1.00
100,000	317	0.32
1,000,000	1,000	0.1

This tabulation shows that some compromise is usually necessary between the desirability of keeping the dangerous activity low and the desirability of obtaining a high count for accuracy in a reasonable time interval.(The effect of the total count on the probable accuracy of the probe as delivered and tested is shown on Figure 4.)

The energy level, usually expressed in million electron volts (MEV), of the gamma-ray emitter is also of importance. Gamma rays are dissipated by matter by a number of different processes. These processes are somewhat related to the mass density of the material, however for gamma rays between about 0.1 and 1.0 MEV the dissipation of the gamma rays is significantly related to the mass density of the medium. For this reason, it was desirable to select a gamma-ray emitter which had an energy level in the range mentioned. After studying the isotopes commercially available, the contractor selected radium 226 as the gamma-ray source. Radium 226 has a gamma radiation at 0.19 MEV, which is in the energy range desired. It also has the added advantage of a half-life of 1590 years, which means that no correction has to be applied to the device from month to month due to decay of the energy source. Other isotopes are available in the desired energy range, however, for the most part they have a short half-life (usually days, weeks, or months) which would necessitate continual correction to the calibration of the probe.

The contractor tested various probe arrangements in pure water and in a meta-sodium silicate (water glass) solution at a specific gravity

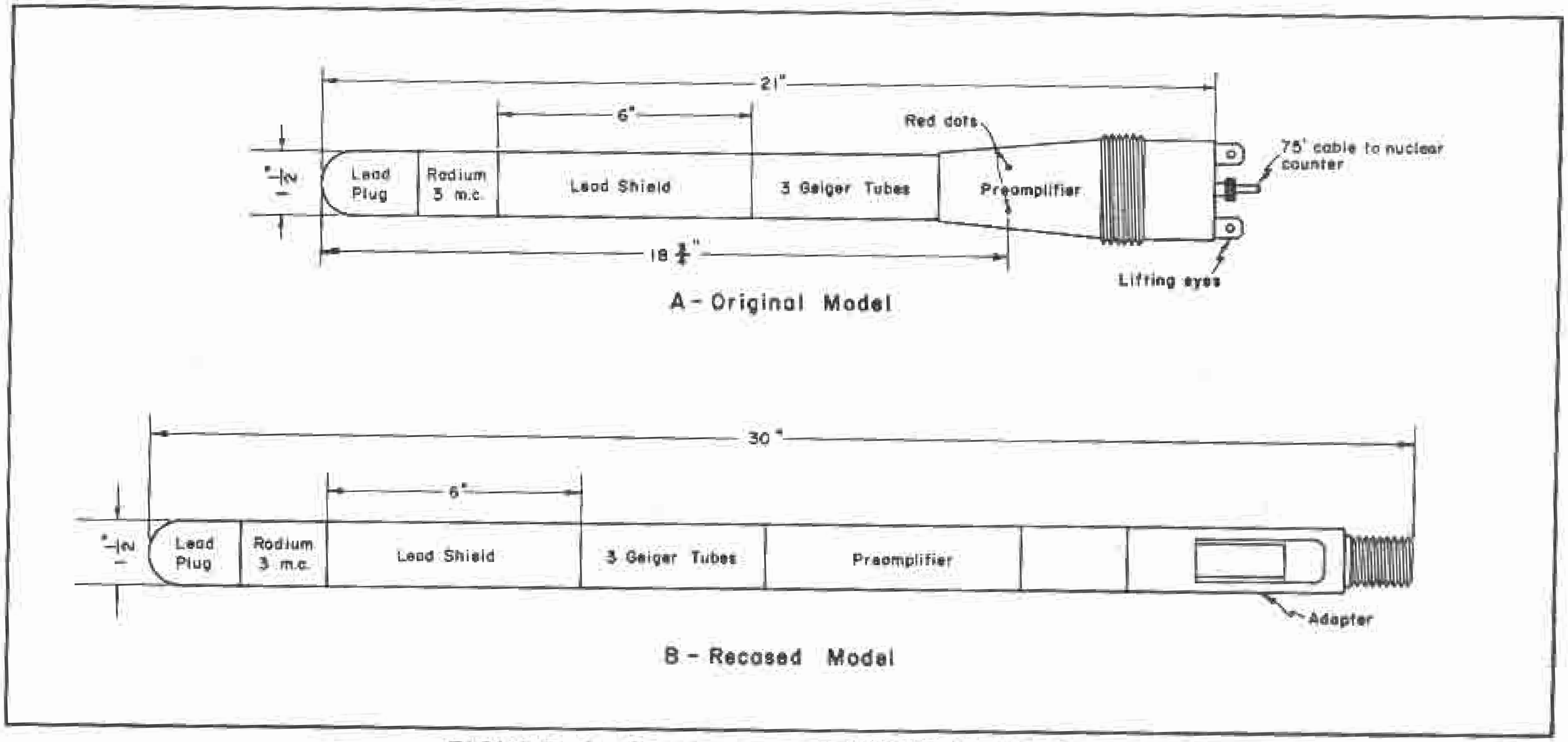
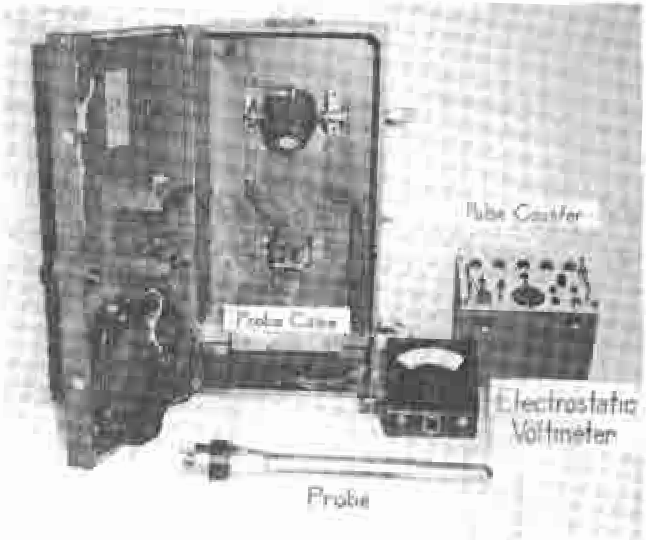
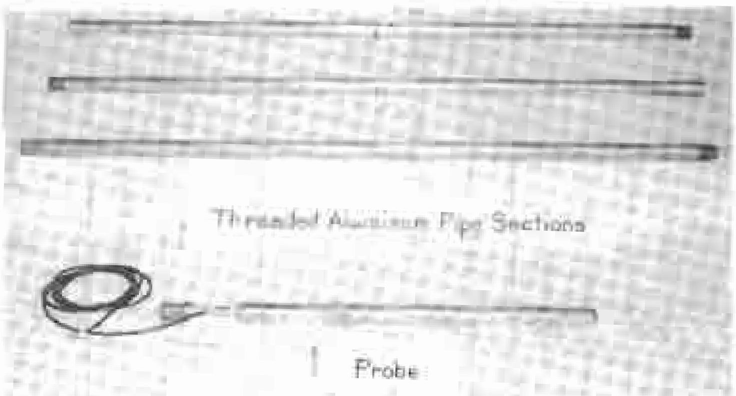


FIGURE 2. SCHEMATIC LAYOUT OF PROBE



A - Original Model



B - Recased Model

FIGURE 3. SEDIMENT DENSITY PROBE

of about 1.4. This range approximated the range of specific gravities given in the design specifications. These tests indicated that a 3-millicurie source of radium 226 would give approximately 18,000 counts per minute in water and 13,000 counts per minute in the water glass solution. This level of activity was selected as a compromise between a safer level but lower accuracy at a 1-millicurie level and a greater accuracy but more danger at a 10-millicurie level.

Probe Dimensions. Tests by the contractor indicated that a separation of about 8 inches between the radioactive source and the counters gave optimum results in terms of accuracy in discrimination between different densities. The intervening 8-inch section in the probe barrel was filled with a 1-inch plastic spacer, a 6-inch lead plug, and a second 1-inch plastic spacer. Figures 2 and 3 show schematic layouts and photographs respectively of the probe, including the original model delivered by the contractor and the recased later model.

The effect of the diameter of the probe on its operating characteristics was also investigated. The contractor had been limited to a maximum diameter of 3 inches in the specifications. The contractor's tests showed that the probe action was relatively independent of probe diameter up to a diameter of about 1-1/4 inches with the sensitivity gradually decreasing as the diameter becomes greater. The probe, as constructed, has a diameter of 1-1/2 inches.

The wall thickness and wall composition of the barrel of the probe also affect its sensitivity. Walls of paper-based Bakelite, of brass, and of stainless steel were tested. These tests led to the selection of 0.065-inch stainless steel barrel, or case, for the probe as being the best compromise between the requirements of high physical strength and low absorption of the gamma rays. The case is rounded at the bottom to enable the probe to penetrate the bottom sediments. The bottom 2 inches or so of the probe (below the radium source) is filled with a lead plug to give it additional strength and to minimize the escape of gamma rays in that direction.

Detectors. The gamma rays backscattered to the probe by the surrounding medium can be detected either by Geiger-Muller counters or by scintillation counters. The ruggedness and simplicity of the Geiger-Muller tubes recommended their use instead of the more sensitive scintillation counter. The final arrangement involved using a cluster of three Geiger-Muller Counters (Type Anton 309). These are thin-walled halogen-filled tubes of small diameters (5/8 inch) operating at about 1,000 volts. These halogen-filled counters have the advantage of a virtually unlimited life over other types of Geiger-Muller counters which lose sensitively with use. The use of three tubes in a cluster instead of one tube increases the count detected by the probe and thereby the accuracy. The operating voltage required by the counters is imposed by a source built into the scaler mentioned previously.

Preamplification. To insure proper operation of the scaler, it is necessary to amplify the counter signals from the Geiger-Muller tubes before sending the signals through the 75 feet of cable to the scaler. To meet this need, the contractor designed and installed in the probe a small, transistorized, battery-powered preamplifier. This preamplifier is of the cathode-follower type and incorporates a 1.3-volt mercury-cell battery. The drain on the battery is only 70 microamperes and the battery can be expected to last its full shelf life of 2 to 3 years before replacement is necessary.

Electrical Connection. The signal from the probe to the scaler is transmitted by 75 feet of rubber-covered coaxial cable. The cable enters the probe through a water-tight connection. Although a 75-foot length of cable is provided as being sufficient for immediate needs, the preamplifier described above permits a cable up to 200 feet in length to be used between the probe and the scaler without noticeably affecting the calibration.

Mechanical Connections. All the components of the probe are mounted on a frame or chassis which slips into the stainless steel casing. This casing or jacket separates the components from the surrounding medium. In the original model the chassis and the jacket were enlarged to 2-1/2 inches in diameter at the top where provision is made for joining the chassis to the jacket by recessed screws and sealing the connection with a rubber O-ring. The seal was tested for watertightness under a water pressure of 45 pounds per square inch (110 feet of water) and proven satisfactory. This enlarged top also provided two eyelets for suspending the probe from a cable and a set of 2-1/2-inch x 8 standard pipe threads to enable a rigid rod or pole to be connected to the probe.

Operating Instructions. The instructions pertaining to safety precautions necessary in the use and handling of the gage are included as Appendix B to this report. As stated previously, the contractor made only limited tests on the probe in the sense that he used only pure water and water glass at a specific gravity of 1.4. The testing of the probe over a wide range of conditions, first in the laboratory and then in the field, may of course, bring about some modification to these operating instructions.

LABORATORY TESTS

Upon delivery of the probe by the contractor in January 1958, a rather comprehensive set of tests was undertaken in the laboratory of the Beach Erosion Board preparatory to the use of the probe in the field. The calibration of the gage with various muds and bulk chemicals was undertaken. Also, the effects of temperature, degree of submersion, proximity of walls, and the volume of the surrounding mass were investigated. These tests and results thereof are discussed in the following paragraphs.

Basic Calibration. The basic calibration point was considered to be the count obtained with the probe placed in an infinite mass of fresh water at ordinary working temperatures. Theoretical considerations indicated that an available 30 x 40-foot rectangular sump filled to a depth of 10 feet with fresh water was more than adequate to represent this "infinite" mass of water. The probe was then placed at the geometric center of the sump with its lower tip submerged to a depth of 5 feet below the water surface. Once in this position, a series of counts were taken on the scaler. The counts were taken over 1, 5 and 10-minute intervals with most emphasis being on the 5 and 10-minute counts for reasons given previously. The actual counts are shown on Table 1. These results of this series of counts indicated that the calibration, or average count of the probe in an infinite medium of fresh water was approximately 18,250 counts per minute.

TABLE 1

CALIBRATION OF PROBE IN LARGE MASS OF FRESH WATER

Water temperature	Count time minutes	Counts per minute
37°F	5	18349
37°F	5	18345
37°F	5	18325
36°F	10	18216
35°F	10	18240
	35	18276 (Weighted Average)

Note:

Sump was 30 x 40 feet in plan and filled to a depth of 10 feet.
Bottom of probe was 5.0 feet below water surface.
Probe voltage = 1080 volts.

Effect of Submergence. The basic count being established, a test was made wherein the probe was withdrawn from the sump in increments to establish the effect of the degree of submersion on the calibration. The results of this test are shown in Table 2. This table indicates that as long as the red dot markers are 0.5 foot or more below the surface, the count is relatively unaffected by the degree of submersion. It was indicated further that a withdrawal of the probe to the red dots (which are reference marks

18-3/4 inches above the rounded bottom tip of the probe) resulted in a decrease in count of about 190 counts per minute. The effect of any further withdrawal was, however, very pronounced. For practical considerations, almost all subsequent laboratory calibrations were made with the probe submerged to the level of the red dots.

TABLE 2

EFFECT OF SUBMERGENCE ON CALIBRATION OF PROBE

Submergence of red dots in feet	Counts per minute
4.6	18246
1.9	18307
1.0	18250
0.5	18203
0.0	17963
+0.25	16856
+0.50	13654
+1.00	11018
0.0	18156

(Average of the two 0.0 red dot readings = 18060 cpm)

Note:

Probe was in center of a sump which was 30 x 40 feet in plan and filled with fresh water to a depth of 10 feet.

Red dots on probe barrel are 18-3/4 inches from rounded bottom tip of probe.

All readings were taken between 8:30 and 11:30 am on 23 Jan. 1958. Sequence of readings was as shown above. All count times were 10 minutes each. Water temperature was 35°F.

Plus (+) signs in first column indicate elevation of red dots above water surface.

Effect of Proximity of Walls. The effect of the proximity of a concrete retaining wall on the probe reading was determined in the same sump used for the calibration tests. The walls and floor of this sump are of 8-inch reinforced concrete. The results obtained by placing the probe at various locations therein are shown in table 3. These tests indicate that the probe could be placed within 8 inches of the reinforced concrete side wall without being noticeably affected by the presence of the wall. Even at 4-inches the count was reduced only some 155 counts per minute from the count in the middle of the sump.

TABLE 3

EFFECT ON PROBE OF PROXIMITY
OF CONCRETE WALLS

Submergence of probe	Probe location in sump	Counts per minute
Red dots	15.0 ft. from side wall	18171
" "	15.0 ft. from side wall	18140
" "	1.0 ft. from side wall	18088
" "	0.66 ft. from side wall	18138
" "	0.33 ft. from side wall	18000
" "	against side wall	16629
" "	1.0 ft. from corner	18236
" "	0.66 ft. from corner	18212
" "	0.33 ft. from corner	18290
about 9 ft.	In center of sump with tip on bottom of sump	18322 18364
about 8.5 ft.	In center of sump with tip 6" off bottom	18193

Note:

All readings taken 25 February 1958 with water at 35°F.
All count times were 10 minutes each.
Walls and floor of sump are reinforced concrete 8 inches thick.
Red dots are on barrel 18-3/4 inches from rounded bottom tip of probe.

The last three readings in Table 3 indicate that the proximity of the sump to the bottom tip of the probe has little effect on the reading. In fact, the count showed higher than with submergence to the red dots on the surface and more nearly agreed with the "infinite" medium tests shown on table 1.

Effect of Temperature. Within a few days after receiving the probe from the contractor a few observations were made which indicated that the probe had good temperature stability characteristics. However, in making a subsequent series of tests, a set of erratic readings was obtained. A study of the erratic data indicated that a temperature effect was present, and a quick set of tests with this in mind verified this to be the case. The test consisted of allowing the gage to reach the ambient air temperature of

56 degrees F and then submerging it completely in the test sump with water at 35 degrees F. Readings were begun immediately on the scaler. The count was found to be as follows for successive 1-minute intervals:

1-minute interval	Count	1-minute interval	Count
1	14063	9	15632
2	14177	10	15727
3	14484	11	15947
4	14661	12	16523
5	14664	13	17723
6	15063	14	18247
7	15342	15	18285
8	15543		

The readings indicate that the temperature effect was noticeable only when the various parts of the probe were actively adjusting to a new temperature. Evidently within 15 minutes the probe had reached temperature uniformity within the gage as the reading over the 14th and 15th minutes approximated the readings obtained in the previous "infinite" medium readings shown on Table 1. There was no noticeable change after the 15th minute.

Shortly before the detection of the erratic results discussed in the preceding paragraph a defective germanium transistor in the preamplifier in the probe had been replaced by a germanium transistor of identical size and manufacture. It was considered probable that this replacement transistor had introduced the temperature effect; it was accordingly replaced, but this time with a silicone transistor which purportedly was not temperature sensitive. The probe was then tested by submerging it alternately in two identical wooden barrels, one with water at 41 degrees F and one with water at 65 degrees F, all other conditions of testing remaining the same. The probe was first placed in the 41-degree water and left there for 1 hour. Successive counts were as follows:

Interval (minutes)	Counts per minute
0 - 10	18177
10 - 20	18285
20 - 30	18147
30 - 40	18153
40 - 50	18098
50 - 60	18142
Average	18170

The probe was then quickly transferred to the 65-degree water and the following readings at 1-minute intervals over the first 30 minutes were obtained:

1-minute interval	Count	1-minute interval	Count	1-minute interval	Count
1	18346	11	18357	21	18257
2	18241	12	18088	22	18186
3	18197	13	18200	23	18278
4	18199	14	18187	24	18343
5	18145	15	18025	25	18234
6	18225	16	18116	26	18214
7	18063	17	18108	27	18158
8	18168	18	17935	28	18186
9	18160	19	18002	29	18082
10	18425	20	18520	30	18269
Av. 1-10 min.	18217	Av. 11-20 min.	18153	Av. 21-30 min.	18221

A review of the above results indicates no identifiable temperature effect, all variations being within the statistical variation which could be expected. This was true even for the first 3 or 4 minutes when the internal temperature gradient within the probe was the greatest.

TABLE 4

EFFECT OF PREAMPLIFIER VOLTAGE

ON PROBE SENSITIVITY

Voltage	Counts per minute	Change in sensitivity counts per minute per volt
1020	17,862	
		4.7
1040	17,957	
		8.5
1060	18,127	
		4.5
1080	18,216	
		4.2
1100	18,300	
		6.9
1120	18,438	
	Overall sensitivity	5.7

Note:

Probe was submerged to geometric center of a 30 x 40-foot sump filled with water to a depth of 10 feet.
All count times were 10 minutes each.

Effect of Amplifier Voltage. Manufacturer instructions called for a voltage of 1080 volts on the preamplifier in the probe. This voltage is supplied by a power-pack build into the scaler. It was of interest to determine the sensitivity of the probe to this impressed voltage. A test was made in which the voltage was varied in 20-volt steps from 1020 to 1120 volts. The results of this test are given in Table 4. A study of the results shows that over the 100-volt range of the test, the probe was sensitive to the impressed voltage at the rate of 5.7 counts per minute per volt. At the critical range between 1060 and 1100 volts, the sensitivity was 4.4 counts per volt. As the drift in voltage was never found to be more than 5 volts during a given day, the probe and amplifier are considered to be well within workable stability limits.

Size of Test Sample. Since it was impractical to prepare large samples of mud and other chemicals with which to calibrate the probe, a few tests were made to determine the minimum size of laboratory samples which could be expected to give a reliable calibration for field use. Preliminary tests indicated that an ordinary steel drum (22 inches in diameter and 30 inches deep) was probably too small to contain a usable sample. The next larger container which could be easily procured was a wooden barrel 30 inches in diameter and 30 inches deep. The drum and the barrel were set alongside the test sump and filled with water from the sump (and at sump temperature). Successive readings were then taken with the probe submerged to the red dots in the center of the sump, the drum, and barrel. The results of the test are shown in Table 5. The top part of Table 5 indicates that the difference in count between the sump and the 30" wooden barrel was 20 counts per minute, hardly enough to be of any significance. The difference between the sump count and the drum count, however, was 356 counts per minute, showing that the 22" steel drum was too small in size to give a reliable reading. The special comparison at the bottom of Table 5 reinforces this fact by showing the drum count to average some 245 counts per minute less than the barrel count. The results established that the decision to use the 30" barrel as the container for calibration samples was proper. These results, when coupled with the results shown on Table 2, also indicate that - at least in water - the probe senses the density of a sphere of material slightly over 2 feet in diameter centered about the center of the probe.

Calibration of Samples. In order to arrive at a usable calibration of the probe for field purposes, a number of samples of various kinds were brought to the laboratory. The samples were, in each case, large enough to fill the 30" x 30" wooden barrels referred to above. The results of the tests as well as tests in fresh water are shown in Table 6; the samples are described below.

Salt water obtained by dissolving commercial sodium chloride (NaCl) in fresh water.

Potomac River mud obtained by flocculating mud from the raw river water some 2 miles above the head of tide water on the Potomac.

TABLE 5

EFFECT OF SIZE OF TEST SAMPLE ON PROBE READING

Location of probe	Count time in minutes	Counts per minute	Difference from sump count
Sump (1)	5	18112	
Barrel (2)	5	18096	- 16B
Sump	10	18171	
Barrel	10	18208	+ 37B
Drum (3)	10	17814	-394D
Sump	10	18140	
Barrel	10	18058	- 82B
Drum	11	17821	-319D
		Average Difference	- 20B
			-356D

Location of probe	Count time in minutes	Counts per minute	Difference from barrel count
Barrel	10	18191	
Drum	10	18034	-167
Barrel	10	18310	
Drum	10	18001	-309
Barrel	10	18296	
Drum	10	18023	-273
Barrel	10	18221	
Drum	10	17956	-265
Barrel	10	18243	
Drum	10	18020	-223
		Average Difference	-245

(1) A 30 x 40' sump filled to 10' depth.
(2) A 30" diameter wooden barrel filled to 30" depth.
(3) A 22" diameter steel drum filled to 30" depth.

Note:

Submergence in barrel and drum was to red dots on probe casing.

TABLE 6

PROBE CALIBRATION IN VARIOUS MATERIALS

Test Material	Weighed bulk sp. gr.	Count time in minutes		Counts per minute
Fresh water	1.000	10		18214
		10		18257
		10		18342
		10		18156
		10		18132
		10		18214
		10		18156
		10		18152
		10		18168
		10		18192
		10		18231
		10		18207
		10		18348
		10		18288
		10		18260
			Total	273317
			Average	18221
		50		18357
Salt water (NaCl solution)	1.032	10		17600
	1.032	10		17590
	1.031	10		17853
	1.031	50		17769
Potomac River mud	1.036	5		17750
	1.164	5		16079
	1.326	5		13920
	1.164	10		16162
	1.036	10		17871
	1.326	10		14031
Delaware River mud	1.051	5		17578
	1.126	5		16567
	1.263	5		14485
	1.263	10		14594
	1.125	10		16686
	1.051	10		17550
	1.051	10		17726
Saturated silica sand	1.940	5		8263
	1.940	10		8229
Dry slacked lime, $Ca(OH)_2$	0.619	10		16266
Saturated powdered non-crystalline bauxite, Al_2O_3	1.142	10		16475
	1.718	10		10413
	1.718	10		10155
Saturated slacked lime	1.382	10		11925
	1.150	10		14975
	1.382	10		11734
Ferric chloride solution, $FeCl_3$	1.116	10		15404
	1.116	10		15521

Tests were made from 16 January to 17 March 1958.

Delaware River mud obtained from dredged spoil from the Delaware River navigation channel near New Castle, Delaware.

Silica sand obtained from the ocean beach near Beaufort, N. C. This sand had very few impurities.

Dry slacked lime, $Ca(OH)_2$, of commercial grade obtained from commercial sources and a slurry was prepared with fresh water.

Powdered non-crystaline bauxite, Al_2O_3 obtained from commercial sources

Ferric chloride ($FeCl_3$) solution obtained from commercial sources.

In cases where a fluid mixture was being tested, the mixture was kept homogeneous during the test by a wooden propellor driven at an adequate speed by an electric motor. Early tests had shown that this was necessary to insure reliable readings.

The mass specific gravity of the various samples was determined carefully. The sample barrels were first calibrated volumetrically by placing them on a platform scale and filling to various levels with fresh water. The sample was then placed in the barrel, its volume determined by the calibration described above, and its weight by the same platform scales.

The probe was spotted over the center of the barrel and was submerged to the red dots on the barrel. Each observation was for 5 or 10 minutes as shown in Table 6. The timing for all tests was with a reliable stop watch as the interval timer on the scales was not sufficiently accurate for the purpose.

The results of the tests given in Table 6 are plotted on Figure 4. A study of the plot shows that for the Potomac and Delaware mud samples, the bauxite, and the silica sand, the points indicate a straight line relationship between bulk specific gravity and counts per minute, with a slight break in the curve at a specific gravity of about 1.4. The limits of departure of these plotted points from the two straight lines were generally within the limits of the statistical error that can be expected due to the limited duration of the count.

The counts for samples of ferric chloride, calcium hydroxide (slacked lime), and salt water fell outside the plot encompassing the other points. The reason for this departure is readily seen by reference to Table 7. This table shows the mass absorption coefficients of the sixteen elements most predominant in the earth's crust. The mass absorption coefficient is related to the linear absorption coefficient which represents the ability

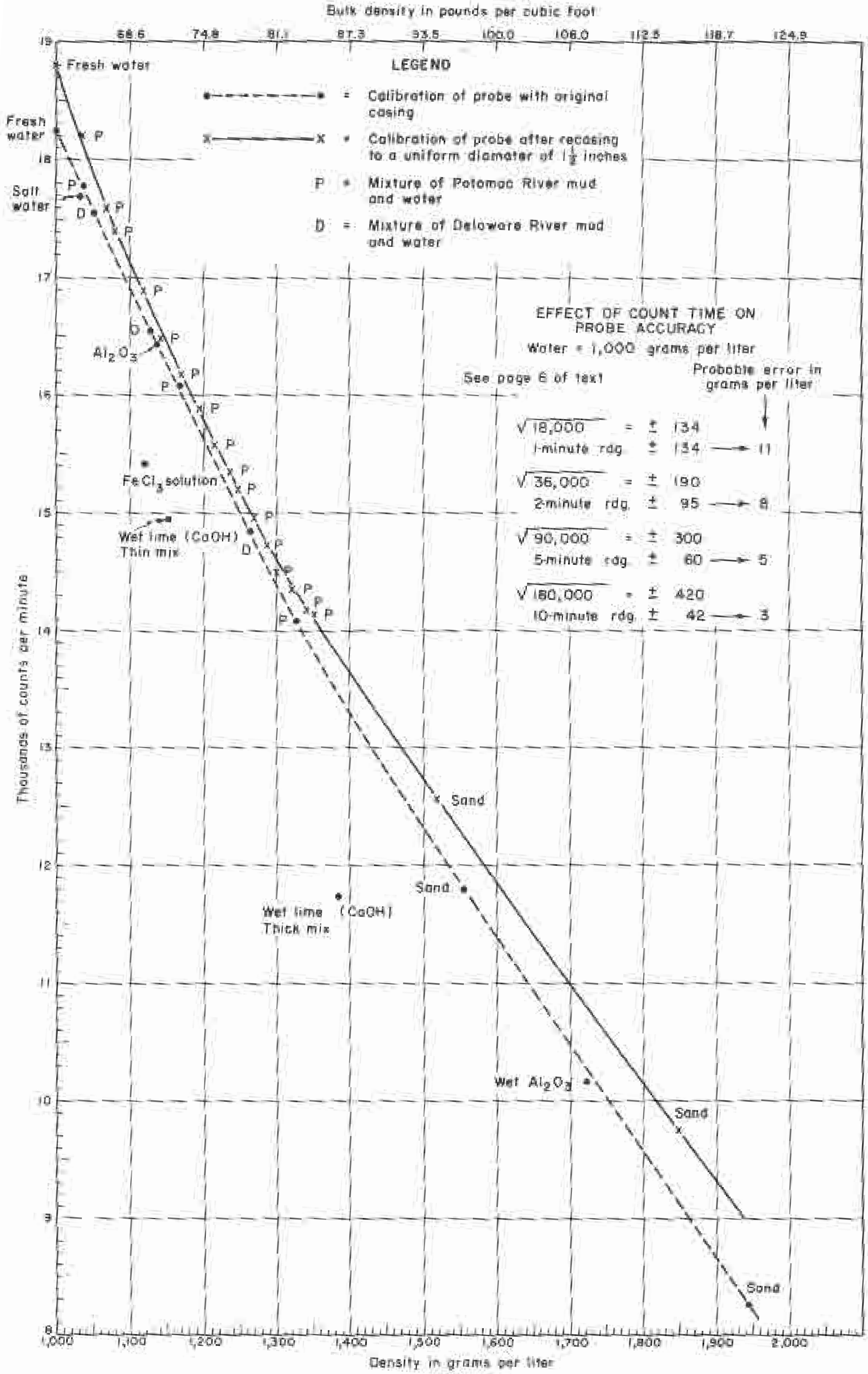


FIGURE 4. CALIBRATION OF SEDIMENT DENSITY PROBE

of the element to absorb or scatter nuclear radiation. The linear absorption coefficient is determined from the equation:

$$\Delta I = -\mu \; I_o \Delta X$$

where I_o = intensity of incident gamma-ray radiation at face of test substance

ΔI = change in gamma-ray radiation during passage through test substance

ΔX = thickness of test material in centimeters

μ = linear absorption coefficient

If I_o is considered as unity and ΔX as 1 cm., the equation becomes:

$$\Delta I = \mu$$

Thus, in effect, the linear absorption coefficient is a measure of that part of the initial gamma-ray flux absorbed by a 1-centimeter thickness of the test substance. Thus, if the absorption coefficient is 0.25, the radiation would be reduced by 25% in passing through a 1-centimeter plate of the test substance. A study of the equation shows it to be exponential in character and that the equation can be expressed as:

$$I/I_o = e^{-\mu X}$$

where I is exit radiation leaving the test substance. The mass absorption coefficient is the ratio of the linear absorption coefficient to the density ρ of the test substance in grams per cubic centimeter. Thus:

$$\text{mass absorption coefficient} = C_m = \mu/\rho$$

Consideration of the above relationships shows that the sediment density probe can be a perfect instrument only if the mass absorption coefficient of all the substances (or elements) being tested is the same. If this were the case, the measured radiation at the Geiger counters would be a measure of the bulk mass of material surrounding the probe. However, if one of the constituent elements is a more effective absorber of radiation than the others, the mass density indication would be unduly influenced by that element and the probe would indicate a bulk density somewhat higher than the true bulk density. Reference to Table 7 shows that of the sixteen elements listed, five have mass absorption coefficients significantly different from other twelve at the 0.200 MEV level. These are iron, calcium, hydrogen, manganese, and barium. Hydrogen is the worst offender; however, in the saturated soils for which the probe was designed, hydrogen is so omnipresent due to the water content, that its influence can be discounted. The other four, however, may appear in varying amounts and thereby distort

TABLE 7

ABSORPTION CHARACTERISTICS OF MOST COMMON ELEMENTS IN EARTH'S CRUST

Order of occurr-ence	Percent of Occurrence (1)	Element and Atomic Number	Symbol and Atomic Wt.	Specific gravity (liquid or solid)	Mass Absorption Coefficient (2) 0.207 A° 0.060 MEV.	0.1242 A° 0.100 MEV.	0.0621 A° 0.200 MEV.	0.0248 A° 0.500 MEV.	0.0124 A° 1.00 MEV.	0.0062 A° 2.00 MEV.
1	46.7	Oxygen 8	O 16.000	1.14	.189	.156	.124	.0870	.0636	.0445
2	27.7	Silicon 14	Si 28.09	2.42	.315	.182	.127	.0873	.0635	.0447
3	8.1	Aluminum 13	Al 26.98	2.7	.270	.169	.122	.0844	.0614	.0432
4	5.0	Iron 26	Fe 55.85	7.9	1.20	.372	.146	.0840	.0599	.0424
5	3.6	Calcium 20	Ca 40.08	1.55	.648	.257	.137	.0885	.0637	.0451
6	2.8	Sodium 11	Na 22.99	0.97	.224	.159	.120	.0836	.0608	.0427
7	2.6	Potassium 19	K 39.10	0.87	.559	.233	.132	.0858	.0619	.0438
8	2.1	Magnesium 12	Mg 24.32	1.74	.253	.168	.125	.0949	.0627	.0442
9	0.62	Titanium 22	Ti 47.90	4.5	.763	.270	.1318	.0814	.0559	.0416
10	0.14	Hydrogen 1	H 1.008	0.07	.326	.295	.243	.173	.126	.0876
11	0.13	Phosphorus 15	P 30.97	2.0 (3)	.340	.185	.125	.0850	.0617	.0436
12	0.09	Carbon 6	C 12.01	2.1 (3)	.174	.152	.123	.0805	.0636	.0444
13	0.09	Manganese 25	Mn 54.94	7.2	1.070	.338	.1382	.0821	.0567	.0414
14	0.08	Sulphur 16	S 32.07	2.07	.400	.201	.130	.0879	.0637	.0448
15	0.05	Barium 56	Ba 137.37	3.5	8.60	2.14	.406	.0970	.0575	.0399
16	0.05	Chlorine 17	Cl 35.46	1.56	.430	.204	.1258	.0841	.0615	.0431
	99.85									

NOTES:

(1) Data taken from "Introduction to Geology," by Branson and Tarr, McGraw-Hill, 1941. Total of percentages for the 16 elements shown is 99.85%.

(2) Absorption coefficients were obtained directly (or by interpolation) from National Bureau of Standards Circular No. 583 "X-Ray Attenuation Coefficients from 10 Kev to 100 Mev." April 1957. Figures are for "coherent scattering". Energy levels are indicated at top of columns both in Angstrom units and in million electron volts.

(3) Approximate value.

the calibration of the probe. This distortion is in evidence in the plotted points on Figure 4 for the ferric chloride solution and the lime slurry.

The import of the above discussion is that the calibration curve of the probe, as drawn on Figure 4, would not hold in event the probe was used in sediments where a significant part of the material was iron, calcium, manganese or barium. Semi-quantitative analyses of the Delaware and Potomac River muds used in the calibration are given on Table 8. Reference to this table indicates that silicon is the dominant element in both muds although some iron and calcium are in evidence, also traces of manganese and barium. The fact that the mud sample readings plotted in a straight line which, incorporating the saturated bauxite, indicates that the iron and calcium content of these samples was not sufficient to noticeably influence the readings.

TABLE 8

ANALYSIS OF POTOMAC AND DELAWARE RIVER MUDS

	Delaware River Mud		Potomac River Mud	
Element	Not Less Than	Not More Than	Not Less Than	Not More Than
	%	%	%	%
Silicon	5.0	50.0	5.0	50.0
Aluminum	1.0	10.0	3.0	30.0
Iron	2.0	20.0	2.0	20.0
Calcium	1.0	10.0	2.0	20.0
Magnesium	1.0	10.0	1.0	10.0
Sodium	0.5	5.0	0.3	3.0
Potassium	0.3	3.0	0.3	3.0
Boron	0.01	0.1	---	---
Lead	0.005	0.05	---	0.03
Tin	---	0.03	---	0.01
Chromium	0.03	0.3	0.01	0.1
Manganese	0.05	0.5	0.03	0.3
Vanadium	0.01	0.1	0.005	0.05
Lithium	0.03	0.3	0.03	0.3
Titanium	0.5	5.0	1.0	10.0
Gallium	0.001	0.01	0.001	0.01
Copper	0.003	0.03	0.003	0.03
Zinc	0.01	0.1	---	---
Zirconium	0.3	0.3	0.1	1.0
Barium	0.01	0.1	0.03	0.3
Uranium	Not detected		Not detected	
Thorium	Not detected		Not detected	

It will be noted that the absorption coefficients in Table 7 are given for several different levels of gamma-ray energy. This is necessary as the absorption coefficient is somewhat dependent on the energy level of the incident gamma rays. Radium 226 emits an alpha ray at 4.795 MEV and a gamma ray at 0.188 MEV. The alpha ray is absorbed by the steel casing of the probe. The gamma ray is partially back-scattered by the surrounding medium and partially absorbed; part of the back-scattered rays reach the Geiger tubes and furnish the count used in determining the bulk density of the material surrounding the probe. The gamma rays at 0.188 MEV are, however, not the only gamma rays emitted from the capsule of radium 226 encased in the probe. As the radium decays through the alpha and gamma emission described above, products of the decay remain within the capsule. Several of these decay products are themselves radioactive and emit gamma rays of even greater energy than the radium 226. The emission spectrum from the radium 226 and its decay products is given below:

Gamma-Ray Energy MEV	Percent of Total Energy
0.188	0.5
0.241	5.0
0.294	11.3
0.350	19.6
0.607	28.8
0.766	2.8
0.933	2.9
1.120	9.0
1.238	2.7
1.379	2.7
1.761	11.3
2.198	3.3

The rather involved energy spectrum complicates any theoretical calculation as to the exact numerical relationship to be expected between the radiation from the radium source and the count detected by the Geiger counters. Thus this report will not attempt a quantitative explanation of the actual count obtained with the probe under various conditions. It is in order, however, to point out that at all levels of energy given in Table 7, the iron, calcium, and chlorine are generally found to have higher mass absorption coefficients that the other elements, excepting, of course, hydrogen. It is also in order to note that the differences in mass absorption coefficients are significantly less at the higher energy levels. This indicates that the departure of the iron, calcium, and chlorine from the other elements could be somewhat nullified by utilizing a radioactive source having gamma energy emission in the 0.5 to 1.0 MEV range only. An example of such a source is cesium 137 with a gamma intensity of 0.663 MEV and a half-life of 33 years with no radioactive decay products. The higher intensity of cesium

137 would, of course, make greater safety precautions necessary and the 33-year half-life would require some adjustment to the probe calibration as the level of radioactivity decayed.

From a usability standpoint, the laboratory tests discussed in the preceding paragraphs showed that the probe had promise of being a useful device for field measurements of bulk sediment density.

FIELD TESTS

Following the completion of the laboratory study and calibration of the probe, field measurements were made with the gage at the following locations with the collaboration of the U. S. Army Engineer District offices as named.

Savannah River tidewater area (Savannah District)

Hulah, Fort Supply, and Denison Reservoirs (Tulsa District)

Landward and seaward of the Chandeleur Islands (New Orleans District)

Navigation channels in San Francisco Bay (San Francisco District)

In addition to the above, a few trials were made in the tidewater area of Potomac River near the Washington National Airport to study the handling characteristics of the probe. The results of these field tests are described briefly in the following paragraphs.

Savannah River Tests. These tests were made from 16 to 18 April 1958. Savannah River went into flood a day or two before the beginning of the tests. Also high winds were blowing over the area. As a result, it was very difficult to hold the boat on location and to place the probe in position on the bottom due to the high current velocities and high winds. Also the flood velocities appeared to have swept most of the soft mud out of the channel. It had been intended to compare the probe readings of density with the density of samples taken by a special mechanical sampler used by the Savannah District, but the flood velocities made reliable sampling with this sampler difficult.

The principal results of these tests might be said to be the finding that the probe could not be used in current velocities of 4 to 7 feet per second and above without special handling equipment. Nevertheless, a few comparative readings were obtained using the two samplers; the results of this work are given in Table 9.

Possibly the most significant result was the close check obtained in the confined sample which had been obtained from the Savannah River and placed in a 32" x 32" open wooden box. Here under controlled conditions, the

TABLE 9

TESTS IN SAVANNAH RIVER

Location	April 1958	Surface to bottom (3)	Surface to probe (5)	Bottom to probe	Duration of count minutes	Counts per minute	Specific Gravity grams per liter: Probe	Specific Gravity grams per liter: Sampler (1) (4)
		Depths in Feet						
City water	16				10	18185	1005	
River water, near surface (5.8 ppt salt)	16		2.0		6	18195	1004	1004(2)
River mud (in box at Engr. Wharf)	16				10	15940	1180	1184(2)
Boat slip at Stevens Ship Co.	16			4.0	10	15610	1205	
	17	25.0	26.2	1.2	3	17007	1096	
	17	"	27.2	2.2	3	16957	1100	
	17	"	28.1	3.1	3	15528	1210	1063
Sta. 140, Sav'h. R. in navigation channel	17	29.0	30.0	1.0	2	17848	1027	
	17	"	32.1	3.1	2	16693	1098	1052
	17	"	36.4	7.4	2	15786	1195	1182
	18 (2:50-3:10PM)	30.0	29.7	-0.3	2	18205	1005	
	18	"	30.7	0.7	2	17029	1094	
	18	"	31.8	1.8	2	16413	1142	1025
	18	"	32.9	2.9	2	16083	1168	1025
	18	"	34.0	4.0	2	15387	1223	1118
	18 (3:10-3:25 PM)	28.0	2.0		2	18418	1000	
		"	28.5	0.5	2	17945	1021	
		"	29.6	1.6	2	17115	1087	
		"	30.6	2.6	2	16682	1122	
		"	31.8	3.2	2	16273	1153	
		"	32.9	4.9	2	15661	1208	
Sta. 215 Sav'h. R. 2 mi. from jetties ocean measurements of water	18 (10:45 to 10:52AM)	30.0	5.0		2	18043	1015	
		"	20.0		2	17994	1017	
		"	30.0		2	18152	1008	

(1) Density of these samples determined in laboratory by pycnometer after procurement by special sampler used in Savannah District.
(2) These samples obtained without use of special Savannah sampler.
(3) Bottom depths not exact.
(4) Sampling with Savannah sampler was not simultaneous with probe readings. Difference in time is as much as 2 hours.
(5) Depth to probe is measured to a point 0.7 foot above its rounded bottom tip.

probe indicated a bulk specific gravity of 1180 grams per liter while a pycnometer determination on the same sample by the District office showed 1184 grams per liter. This indicated that the Savannah River mud contained no significant quantity of the elements which would distort the probe reading.

The probe and the Savannah sampler indicated (as expected) an increase in density with increased penetration in the mud bottom. However, the probe consistently indicated a greater density at comparable penetrations than did the Savannah sampler. It appears that the sampler construction and operation may permit the mixing of some river water with the samples as the sample is being taken; this may account for the lesser specific gravity indicated by the Savannah sampler.

The count of 2 minutes used in most of the sampling is probably the minimum that should be used to avoid undue statistical error.

Tulsa District Tests. Tests were made in September 1958 in Hulah, Fort Supply, and Denison Reservoirs. The purpose of these tests was to determine the amount of sediment being carried into the reservoirs by tributary streams. The results thereof are given in Appendix C.

The tests afforded some comparison between the results obtained with the probe and with a pipe sampling method in use in the Tulsa District. The details of this sampling method are not given, but it entails obtaining an undisturbed field sample which is taken to the laboratory for a measurement of wet and dry density. The comparative results are given on Table C-3 of Appendix C; the dry weight in this table is understood to be the weight of dry solids per cubic foot of the wet sediment mixture as sampled in the field. It should be noted that only the Denison observations are truly comparable in that the pipe sample was taken simultaneously and at the same location as the probe reading. It should also be noted that this set of observations is in much better general agreement than the observations at Hulah and Fort Supply where the sampling was not concurrent.

In the Tulsa District it was found that the flared top and pipe connector on top of the probe made it difficult to push this probe top into the mud. This difficulty was also noted in other areas and steps were taken to remodel the casing of the probe and connectors to a uniform diameter of 1-1/2 inches (see Figures 2B and 3B).

Tests in Chandeleur Islands Area. These tests were made primarily to determine the density of the material settling in a number of test pits dredged in the area. These pits were dredged to determine the rate and character of shoaling to be expected in the projected Mississippi River-Gulf Outlet navigation channel through Chandeleur Sound. The pits were dredged in 10 to 20 feet of water and were approximately 100 x 500 feet. Three pits (C, D, and E) were dredged in Chandeleur Sound and two pits (A and B) in the Gulf offshore from the Chandeleur Islands; all five were dredged to about 30 feet below mean Gulf level.

The results of observations made with the probe in the test pits in January 1959 are given in Appendix D. These results were useful in indicating the character of the shoaling that could be expected in the projected channel. It was of considerable interest to verify that the shoaling was dense enough (1,300 to 1,500 grams per liter) to require dredging. There had been some thought that the shoal material would be so thin that it would not greatly impede the movement of vessels using the channel, but, as shown, this was not the case.

Tests in San Francisco Bay. The survey by the San Francisco District is by far the most extensive use yet made of the probe involving some 350 separate observations. The results of those tests are reported in detail in a report, "Field Use of the Beach Erosion Board In-place Sediment Density Probe", January 1960, prepared by the U. S. Army Engineer District, San Francisco. Copies of the report are available on loan from the District Engineer or the Beach Erosion Board, and no attempt will be made to summarize the results of those tests in this present report. The "Conclusions" of the District's report and comments of the Operations Division Office, Chief of Engineers are given in Appendix E to the present report.

SUMMARY

The laboratory tests showed the probe to give a reliable indication of the in-place bulk density of the sediment surrounding the probe. The fact that the probe senses, or averages, over a sphere of material about 1 foot in radius centered on the center of the probe, tends to minimize the disturbance created by lowering the probe into the sediment.

The presence of certain elements notably (iron, calcium, or chlorine) in larger than ordinary proportions will distort the calibration of the probe and make a calibration for the particular sediment necessary. No natural sediments were encountered in the laboratory calibrations or field tests which contained enough of these elements to require a special calibration of the probe.

Three improvements in the probe and auxiliary equipment appear worthy of additional thought.

(1) A better clock switch to start and stop the scaler is needed. The accuracy should be better than 0.1 second per minute, as errors of this magnitude have a considerable influence on the density determination. The use of a stop watch, instead of the built-in clock switch on the scaler, is not completely satisfactory.

(2) The use of an isotope with a higher energy gamma ray (possibly in the order of 1 MEV) could be expected to improve the calibration of the probe with respect to sediments with iron, calcium, or chlorine content. Cesium 137 with a gamma ray of 0.663 MEV and a half-life of 33 years might be suitable isotope in this regard. This higher energy gamma emitter would, of course, necessitate additional safety precautions.

(3) The use of a greater quantity of radioactive material in order to increase the rate of counting, would give greater statistical accuracy. This would be particularly useful in improving the accuracy in 1 and 2-minute observations. Here again, additional safety precautions would be necessary.

(4) The physical shape of the probe could be improved by eliminating the bulge at the top provided for handling gear. This would enable greater penetration of the probe into the bottom. (The probe at the Beach Erosion Board has been recased to provide a uniform diameter of 1-1/2 inches from the rounded lower tip to the top. See Figures 2B and 3B. The calibration curve of the recased probe is shown on Figure 4.)

(5) Improvements in handling methods in the field are desirable. It can be expected that these improvements will come with increased use of this type of probe.

All in all, the probe gives evidence of being an accurate and practical tool for determining in-place bulk densities of saturated sediments in the field. There is considerable evidence that its accuracy is greater and the cost per determination less than those of other methods presently in use.

APPENDIX A

INSTRUCTIONS TO CONTRACTOR

WORK TO BE DONE:

The contractor shall furnish all materials, supplies, equipment, labor and supervision, and perform all work for conducting a research study for the investigation development, and production of a sediment density probe which utilizes the scattering and/or the absorption of gamma radiation for density measurements.

The contractor shall develop and deliver the above-described instrument, utilizing his best efforts to meet or exceed the following minimun operating characteristics:

a. Minimum count rate with the probe immersed in water to be not less than 10,000 counts per minute.

b. Weight of the probe, exclusive of the connector cable, to be not more than 40 pounds.

c. Length of the probe not to exceed three feet.

d. Diameter of the probe not to exceed three inches.

e. Exterior of probe to be streamlined design with rounded conical point at the leading end.

f. Gamma radiation source not to exceed 20 millicuries of Radium, Cobalt - 60, or equivalent.

g. Radiation source to be encapsulated in stainless steel.

h. Exterior of probe to be corrosion-resistant material consistent with immersion in saline water.

i. Significant vertical resolution of the probe not to exceed two feet.

j. Average accuracy of probe to be plus or minus 1.0 pound per cubic foot for sediments containing from 2 to 35 pounds of soil solids per cubic foot.

k. Incorporation of a preamplifier in the design of the probe to permit use of connector cables up to 75 feet in length.

l. Probe design capable of withstanding hydrostatic pressures of as much as 75 feet of head.

m. Probe design sufficiently ruggedized to minimize malfunction, repair and replacement of component parts as a course of normal usage.

The degree of attainment of the above listed characteristics shall be consistent with the present state of the art of utilizing gamma-ray scattering techniques.

(The above provisions are extracted from the development contract which resulted in the design and production of the first model of the radioactive sediment density probe.)

APPENDIX B

SAFETY REQUIREMENTS FOR RADIOACTIVE SEDIMENT DENSITY PROBE

The following instructions pertain to safety precautions necessary in the use, handling, storage, and repair of the Beach Erosion Board radioactive sediment density gage:

a. The radioactive sediment density gage employes 3 millicuries of radium encapsulated in a stainless steel container and a plastic shroud. The radioactive source is placed approximately 3 inches from the rounded tip of the probe. While this quantity of radioactive material should present minimum hazards, careful handling is necessary in order that any potential accident or overexposure be eliminated. The instructions given below shall be followed at all times:

b. When the probe is stored the following precautions are necessary:

(1) The probe shall always be placed in its lead shield such that the tip containing the radioactive source is completely incased by the lead shield.

(2) The probe and lead shield shall always be placed in the special carrying box and the box shall be locked at all times.

(3) The box shall be stored in a locked ventilated building where no personnel are housed. Only authorized personnel shall have access to the building and the building is to be properly marked by signs indicating radioactive material.

(4) In the event personnel are in the storage building, the case shall be properly marked and under no circumstances shall personnel be allowed to sit on the case.

c. When the probe is in use the following precautions are necessary:

(1) All personnel who work with or near the probe must wear a dosimeter at all times. Exposure as determined by dosimeter reading shall be recorded as outlined in AR 40-431.

(2) Personnel shall not stand closer than 3 feet to the probe when the probe is out of its lead shield. The person handling the probe shall always hold the probe such that the rounded end containing the radium capsule is always directed away from his body.

(3) The probe shall be handled only from the top end (cable end), the hands being kept as far from the tip as possible. Under no conditions shall operating personnel grasp the probe along its lower 1 foot (within 1 foot from the rounded end).

(4) If repairs are required, the source area of the probe shall be incased in the lead shield. If this action is impractical, the lower 1 foot of the probe shall be placed behind lead brick and a mirror shall be placed behind the probe in order to see the probe while working. If this also is impractical, the radium capsule shall be removed from the probe and stored in a shielded locked location. However, it is of utmost importance that the radium capsule shall never, under any conditions, be handled or be allowed to touch any portion of the body. Mechanical devices such as long-handled tongs shall always be employed when working with the radium capsule.

(5) The maximum permissible weekly dose for personnel working with radioactive material is 300 millirem, or 3 rem per 13 weeks. Persons receiving a greater dose should immediately report the fact to their supervisor.

(6) The supervisor should check all personnel dosimeters each week the probe is in use and record the findings on DD Form 1141. The supervisor shall arrange for proper actions in the event of overexposure.

d. In the event a man receives a dose of 300 millirem in any time less than one week, any activities of that man connected with the sediment density gage shall immediately be suspended until the appropriate 7-day period has been completed.

APPENDIX C

TESTS IN TULSA DISTRICT

Extract from report of Francis W. Kellum, Electronic Technician, on field trip to Tulsa District.

Arrived at Hulah Reservoir on September 9, 1958. Carried pipe for lowering probe, all 3/4-inch diameter, three pieces 10 feet long and two pieces 5 feet long. Also took a rig designed for lowering current meters by a steel cable.

We found that by just using the cable we could penetrate the sediment by 2 to 3 feet, but that by using the pipe to force the probe down, there seemed to be no limit to the depth that we could penetrate as long as there was a sediment deposit.

The method we used to get our data is as follows:

(a) Measure our water depth with a steel tape to which was attached a weight. The measurement may not be highly accurate due to the weight sinking into the soft upper sediment.

(b) Turn on the scaler, which was attached to the sediment density gage by an electric cable, and set the voltage to gage to 1080 VDC.

(c) Lower the gage into sediment to the desired depth, either by cable or by pipes.

(d) Turn the count switch on at the same time start a stopwatch.

(e) After 5 minutes turn count switch off and record the number of counts from the scaler.

Out in the open water we had some wind and being in a small boat we had some trouble keeping the boat still and with the pipe had trouble holding on. When in a protected area, the pipe method of placing the probe into the sediment worked fine. When the probe was forced down very deep into the sediment it was hard to pull up, in other words, the probe goes down easier than it comes up. If the wind was blowing very hard it would be very difficult to retrieve the probe if forced very far into the deposit.

Worked in Fort Supply Reservoir on September 11, 1958. The gage worked fine and the water counts agreed with those taken at Hulah Reservoir.

Test data are given in following tables C-1 and C-2.

TABLE C-1

TESTS WITH RADIOACTIVE SEDIMENT DENSITY PROBE
AT
HULAH RESERVOIR

Range	Station	Water Depth	Depth to Probe Tip	Probe Tip in Sediment	Total Count	Time (min)	Cycle per min.	indicated* specific gravity	Date
Test in water			2.0	0.0	91,792	5	18,358		9/9/58
1 (a)	main channel	24.5	26.8	2.3	63,900	5	12,780	1.464	9/9/58
2		32.0	25.0	3.0	70,562	5	14,112	1.336	9/9/58
Test in water			2.0	0.0	18,740	1	18,740		9/9/58
			2.0	0.0	18,677	1	18,677		9/9/58
3 (b)		20.5	32.2	1.7	68,422	5	13,684	1.370	9/9/58
Test in water			2.0	0.0	92,088	5	18,418		9/9/58
4		29.0	31.0	2.0	68,572	5	13,714	1.367	9/9/58
		29.0	35.5	6.5	60,980	5	12,196	1.526	9/9/58
5		27.8	30.5	2.7	65,970	5	13,194	1.418	9/9/58
6		28.5	31.0	2.5	68,999	5	13,800	1.360	9/9/58
		28.5	34.5	6.0	64,286	5	12,857	1.456	9/9/58
7		25.0	27.5	2.5	67,361	5	13,472	1.389	9/9/58
		25.0	29.5	4.5	65,590	5	13,118	1.427	9/9/58

NOTES;

(a) Slightly windy and boat rocking makes volt meter needle vary over 1080 ± 5

(b) Very light breeze approximately 250 feet from right bank.

* The indicated specific gravity is corrected by subtracting the water count in cycles per minute as shown on the graph from the average of the water counts taken at both reservoirs, and this difference then subtracted from the counts taken in the sediment and applied to the graph. The reservoir water count is 184 counts higher than the 18,220 used on the calibration graphs.

TABLE C-2

TESTS WITH RADIOACTIVE SEDIMENT DENSITY PROBE
AT
FORT SUPPLY RESERVOIR

Range	Station	Water Depth	Depth to Probe Tip	Probe Tip in sediment	Total Count	Time (min)	Cycle per min.	indicated* specific gravity	Date
Test in water			2 ft.	0.0	91,791	5	18,358		9/11/58
		12.5	14.5	2.0	65,449	5	13,090	1.430	9/11/58
1 (a)		12.5	16.5	4.0	67,227	5	13,445	1.380	9/11/58
3		14.5	17.5	3.0	72,857	5	14,571	1.300	9/11/58
Test in water			2 ft.	0.0	91,789	5	18,358		9/11/58
5		12.2	15.5	3.3	72,299	5	14,460	1.308	9/11/58
9		5.5	7.5	2	71,166	5	14,233	1.325	9/11/58
25 (b)	14 + 00	0.0	2.0	2.0	62,643	5	12,529	1.490	9/11/58
25 (c)	15 + 60	0.0	2.2	2.2	50,823	5	10,165	1.755	9/11/58
25 (d)	15 + 72	0.5	2.7	2.2	43,304	5	8,661	1.919	9/11/58

NOTES:

(a) Cloudy-cool-calm

(b) Over bank deposit about 2 feet thick. Sediment is dark silt or clay, dry on surface. Quite difficult to push to this depth.

(c) At edge of channel at toe of bank. Deposit was fine sand and appeared saturated with water.

(d) At low point in channel. Fine sandy material. Probe went down too rather easily, but rather difficult for one man to pull out.

* The indicated specific gravity is corrected by subtracting the water count in cycles per minute as shown on the graph from the average of the water counts taken at both reservoirs, and this difference then subtracted from the counts taken in the sediment and applied to the graph. The reservoir water count is 184 counts higher than the 18,220 used on the calibration graphs.

ADDRESS REPLY TO:
DISTRICT ENGINEER
U. S. ARMY ENGINEER DISTRICT, TULSA
P. O. BOX 61
TULSA 2, OKLAHOMA

U. S. ARMY ENGINEER DISTRICT, TULSA
CORPS OF ENGINEERS
616 SOUTH BOSTON
TULSA 2, OKLAHOMA

REFER TO FILE NO. SWP WH

22 DEC 1958

SUBJECT: Sediment Density Probe Test

THRU: Division Engineer
U. S. Army Engineer Division, Southwestern
Dallas, Texas

TO: Chief of Engineers
Department of the Army
Washington, D. C.

1. Reference is made to 4th Ind, dated 8 August 1958, to letter SWPWH dated 3 July 1958, subject, "Request for Tests of Reservoir Sediment Density by Means of Sediment Density Probe", in which it was requested that Tulsa District prepare a report regarding performance of subject instrument upon completion of the tests. A description of the tests, summary of results and comments regarding the probe's performance follow.

2. The sediment density probe developed at the Beach Erosion Board and its accessory equipment were used for a 2-week period in the Tulsa District. Information on the probe and its operation is contained in Report No. TOI58-5 dated March 1958, subject, "Final Report on Development of a Sediment Density Probe" by I. L. Kofsky, Ohio River Division Laboratories, Corps of Engineers. Copies of the report may be obtained from the Beach Erosion Board. Mr. Francis Kellum, Electronic Instrument Technician with the Beach Erosion Board worked with personnel to familiarize them with the equipment and its use during the first week of the test. Other persons participating in the work were Mr. A. S. Dowdy, Southwestern Division and various personnel from the Tulsa District Office. The following equipment was used in addition to that provided by the Board: The Division boat normally used for sedimentation surveys and a boat anchor; several 6-foot lengths of 3/4-inch galvanized iron pipe used in shallow water areas to push the probe into the sediment; a sounder reel with reel boom, used for raising and lowering the probe in deep water areas.

3. The sediment density probe operates on the principle that the amount of scattering and absorption of gamma rays in any medium is a function of the density of the medium, so the density can be found from the number of gamma rays that are registered by a Geiger counter placed a few inches from a radioactive source. The count is recorded on a nuclear scaler which is connected by a 75-foot electrical cable to the Geiger counter in the probe. The count is measured for a 5-minute period to increase the accuracy of the observation.

4. The Beach Erosion Board made a series of tests with the probe in materials of known densities to develop a curve from which mass density can be read after the rate of count has been determined. This is a "wet density" value which must be converted to "dry density", or weight of sediment per unit of volume, to determine the weight of sediment in the reservoir. This can be done if the specific gravity of the material is known. A value of 2.65 was used by this office as the mean specific gravity of sediment and a curve for determining dry density was developed. A copy of the curve is inclosed (Inclosure 1).

5. Sediment density measurements were made with the density probe at several locations in Hulah, Fort Supply and Denison Reservoirs. At Hulah and Fort Supply Reservoirs the measurements were made at approximate locations where undisturbed samples of sediment had been obtained with the Southwestern Division sediment sampler during the 1958 surveys of the reservoirs. At Denison Reservoir a sample was taken for laboratory determination of dry weight at the same time and location that a measurement was made with the sediment probe. The probe measures the density of a spheroid-shaped segment of material approximately 16 inches long in the direction of the axis of the probe and perhaps 30 inches perpendicular to the probe. This limits the minimum depth of sediment which can be measured to about 1.5 feet. At locations where there was more than four feet of sediment, density measurements were taken at two depths. Results of the measurements with the probe are shown in Inclosure 2 along with laboratory analysis of density of samples taken at or near the location of the measurements. These samples and measurements shown in this table were taken at depths of 0.5 foot to 2.5 feet below top of sediment. Variations between the probe measurements and laboratory analysis of dry weight were much greater at Hulah and Fort Supply than at Denison. It is believed that this is because in Hulah and Fort Supply Reservoirs the measurements and samples were not taken in the same locations. Inclosure 3 shows the results of measurements with the probe at different depths in the same location and shows the relationship of increase in density to sediment depth.

6. It is estimated that a 3-man crew could take density measurements with the probe at about 12 locations per day in Hulah Reservoir, or one of similar size, measuring density at two depths at about half of the locations and at one depth at the others. If samples are desired for grain size analysis they could be obtained during the measurements with no appreciable increase in time. With the Division sampler it is estimated that two men could obtain samples at the locations in about 5 hours. Only one sample per location would be taken, since the depth of sampling is largely uncontrolled. The laboratory charge for dry weight analysis is \$6.50 to \$7.00 per sample. Assuming an average hourly pay rate of \$4.00 and excluding equipment charges for which a

reasonable estimate is not known, the estimated cost for each density measurement with the probe is about $5.30 as compared to $10.00 per density determination using the sampler.

7. Although the probe appeared to perform capably in uncompacted underwater sediment, the condition for which it was designed, it appears to have certain disadvantages and limitations in measurement of reservoir deposits as follows:

a. The minimum depth of sediment that can be tested is about 1.5 feet.

b. When operating in deep water where the probe is let down with a sounding reel, the deepest penetration into the sediment obtained during the test was about 3 feet. Deposits several times this depth may be expected. With pipe attached to the probe it could be pushed to a depth of about 10 feet and recovered manually from the work boat. About 30 to 40 feet of pipe was all that could be handled while working from the boat. More pipe could probably be used, and greater penetration obtained, if work is done from a raft and a mechanical lifting aid is devised.

c. The boat should be firmly anchored while the measurement is being taken. This is difficult to accomplish because the smooth reservoir bed allows the anchor to slip. Pitching of the boat during windy weather makes it extremely difficult to handle the probe with pipe attached.

d. In an area of the Cumberland Pool delta in Denison Reservoir where deposits had been air-dried but were covered with water at the time of test, two men could push the probe only about 2 feet into the 5 feet of deposited sediment.

e. The probe will not give accurate density measurements in deposits which are exposed to the air, as air voids between the sediment particles cause an erratic count. Exposed deltas form an important part of the sediment deposits in many reservoirs.

f. It was difficult to connect the electrical cable to the probe with the plug provided. The plug was waterproofed to prevent moisture from entering the connection but a leak developed during the test. This part could very likely be improved in final design.

g. The probe is designed with a flared top end and threaded for a 2½-inch pipe coupling which is attached when the probe is to be pushed into the sediment. The bulky connection greatly increases resistance to penetration through the sediment and this part of the equipment needs further streamlining.

h. There is a danger to personnel of overexposure to radiation from the radioactive source if the probe is handled carelessly.

8. In summary, the probe appears to perform very well in underwater sediment which has not been air-dried. Within certain limits it can be used to determine density of sediment at different depths, which would increase the accuracy of reservoir sediment weight determinations. The equipment is bulky, requires specially trained personnel to maintain, and damp or windy weather interferes with its operation. It would be necessary to use the sediment sampler presently in use in addition to the probe on most reservoir surveys to obtain data on density of delta deposits and to obtain samples for grain size analysis. The cost, excluding equipment charges, of obtaining a density measurement with the probe is considerably less than the cost per sample with the present equipment.

9. For the time being, it is recommended that a sediment density probe not be procured for use in Tulsa District Reservoirs. However, it is further recommended that views of the Tulsa District outlined above be considered if there is a redesign of the probe and if a probe is procured at a later date for use by the Southwestern Division Sedimentation Survey Party Chief.

John D. Bristor

JOHN D. BRISTOR
Colonel, CE
District Engineer

3 Incls (quad)
1. Sediment Density Curve
2. Table - Results of Test
3. Table - Density Related to Depth

SWDGB-8 (812.5 A-18) 1st Ind
SUBJECT: Sediment Density Probe Test (Tulsa ltr, 22 Dec 58)

US Army Engr Div, Southwestern, Dallas, Tex, 22 Jan 59

TO: CofEngrs, DA, Washington, D. C. 23 Jan 59

1. Forwarded for information.

2. In view of the imperfections in the sediment density probe and the limitations of its use found during the testing period in the Tulsa District and described in paragraph 7 of the basic letter, this office believes that use of the probe in the Southwestern Division would not be practical at this time. However, it is also believed that its use in most of the future field sedimentation resurveys would warrant further consideration if some of the deficiencies are corrected. At such time that the probe is perfected, this office would be interested in further testing the equipment with the view of procuring same, providing the cost is practical and funds are available in the Division.

FOR THE DIVISION ENGINEER:

RDField

R. D. FIELD
Chief, Engineering Division

3 Incl
w/d 1 cy ea

CC
Tulsa

NOTE BY BEACH EROSION BOARD:

The Tulsa District tests were made before the probe was recased to a uniform diameter of 1-1/2 inches and before threaded pipe sections of 1-1/2 inch pipe had been provided for handling the probe.

TABLE C-3

DENSITIES OF RESERVOIR SEDIMENT DEPOSITS
COMPARISON OF LABORATORY ANALYSES AND
SEDIMENT PROBE TESTS

RANGE NO.	Dry Weight, lbs/cu.ft.		Wet Weight, lbs/cu.ft.	
	Laboratory Analysis (1)	Sediment Probe (2)	Laboratory Analysis (1)	Sediment Probe
		FORT SUPPLY RESERVOIR		
1	41.3	38.0	85.9	85.5
3	33.5	28.5	81.8	80.2
5	63.9	29.5	101.4	80.8
9	38.5	31.5	85.4	81.7
25(3)	77.5	46.5	108.6	91.7
		HULAH RESERVOIR		
1	50.7	44.2	89.4	90.0
2	37.6	32.2	80.8	82.6
3	52.8	35.8	89.7	84.5
4	42.1	35.6	83.6	84.5
5	40.7	40.0	83.6	87.5
6	41.5	34.8	84.3	83.8
7	40.4	37.6	82.1	85.6
		DENISON RESERVOIR		
14	72	79	107	110
14	89	85.5	121	115
14	46	49	90	94
15	77	79	112	110
Hwy. 99 Bridge, Washita Arm (3)				
	58	67	98	104

(1) Samples of Denison Reservoir sediment were taken with pipe sampler for laboratory analysis at the time and location of sediment probe test. At Ft. Supply and Hulah Reservoirs samples of sediment for laboratory analyses were obtained about 3 months earlier and probe was tested in general area sampled.
(2) Based on an assumed specific gravity of 2.65 for sediment.
(3) Surface of sediment was above water level.

TABLE C-4

COMPARISON OF SEDIMENT DENSITY
AT DIFFERENT DEPTHS USING
SEDIMENT DENSITY PROBE

LOCATION (Approximate)	Penetration, Tip of Probe (Feet)	Density of Sediment	
		Wet (lbs/cu ft)	Dry (1) (lbs/cu ft)
DENISON RESERVOIR:			
Range 14, Sta. 35+00	2	94	49
Range 14, Sta. 35+00	7	101	62
Hwy 99 bridge, Washita Arm	2	104	67
Hwy 99 bridge, Washita Arm	5	114	83
HULAH RESERVOIR:			
Range 3, main channel	1.5	84	36
Range 3, main channel	5	90	44
Range 4, main channel	2	84	36
Range 4, main channel	6.5	94	50
Range 6, main channel	2.5	84	35
Range 6, main channel	6	90	44
Range 7, main channel	2.5	86	38
Range 7, main channel	4.5	88	41

(1) Based on an assumed specific gravity of 2.65 for sediment.

Beach Erosion Board Comment: Right-hand column gives the estimated pounds of dry sediment per cubic foot of the wet mud mixture.

APPENDIX D

TESTS IN CHANDELEUR ISLANDS AREA

As a guide to the selection of the route of the Mississippi River-Gulf Outlet, the New Orleans District made certain sediment studies along the various routes proposed. One feature of these studies was the dredging of five test pits measuring 100 x 500 feet, the long dimension being parallel to the proposed channel alignment. Three of these pits were dredged in Chandeleur Sound and two in the Gulf of Mexico immediately outside the Chandeleur Islands chain. The locations of the pits are shown on Figure D-1.

The pits began to shoal immediately after dredging. This shoaling action was followed closely by periodic surveys using both leadline and echo sounder. After considerable shoaling had taken place a set of observations were taken in the pits themselves; however, a few were taken in the undisturbed bottom areas adjacent to the pits.

The results of these density observations are shown on Figures D-2 thru D-5. No probings were made in Pit B.

It will be noted that in a few cases the probe showed a compact layer overlain and underlain by layers of less density. The differences in these densities was well outside the statistical inaccuracy of the probe and these densities are therefore considered to represent the actual situation.

There was some difficulty in handling the probe in wave action, particularly in the Gulf; however, this was before the probe had been recased to a uniform diameter of 1-1/2 inches and the threaded 1-1/2-inch pipe provided for handling the probe.

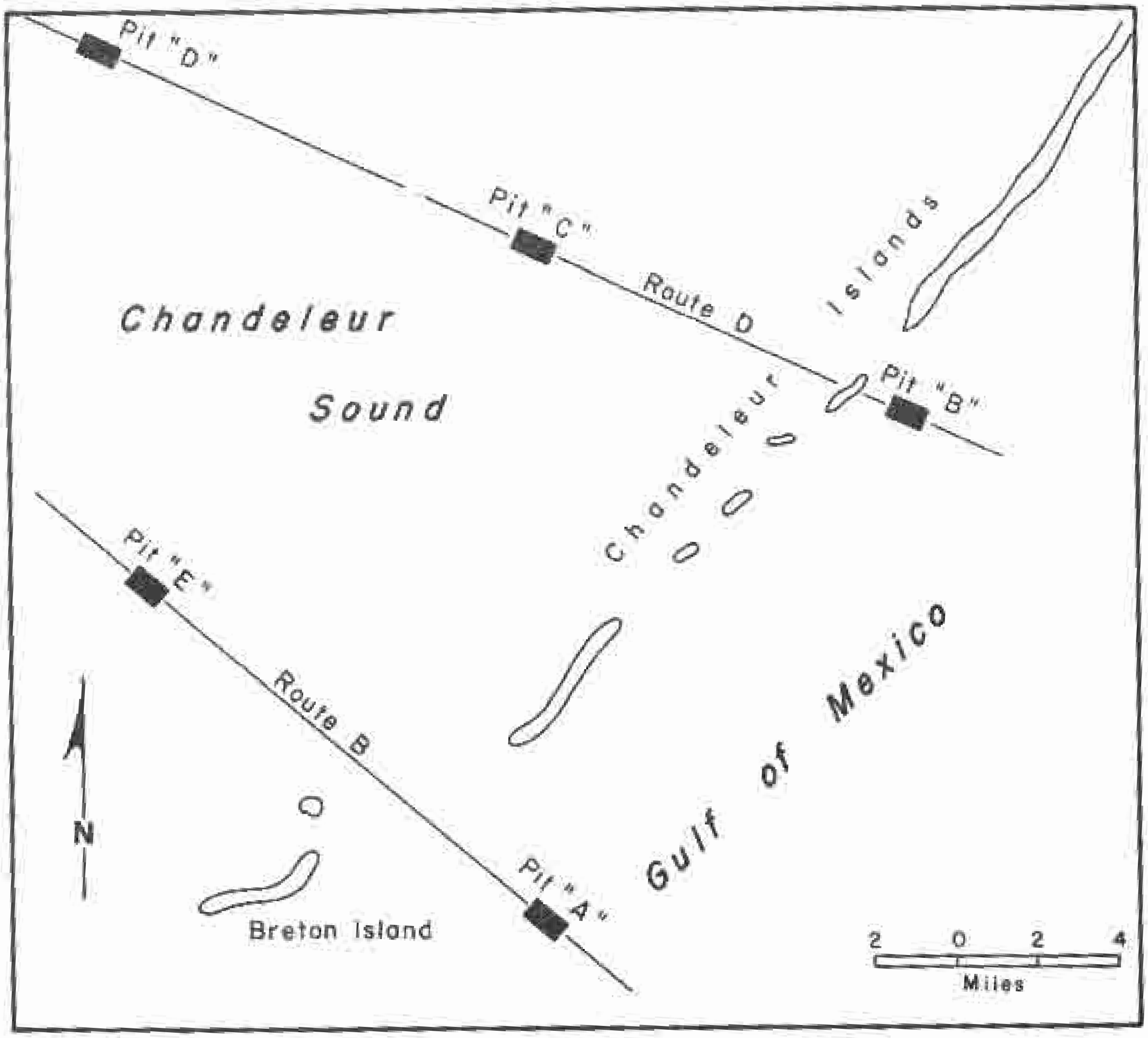
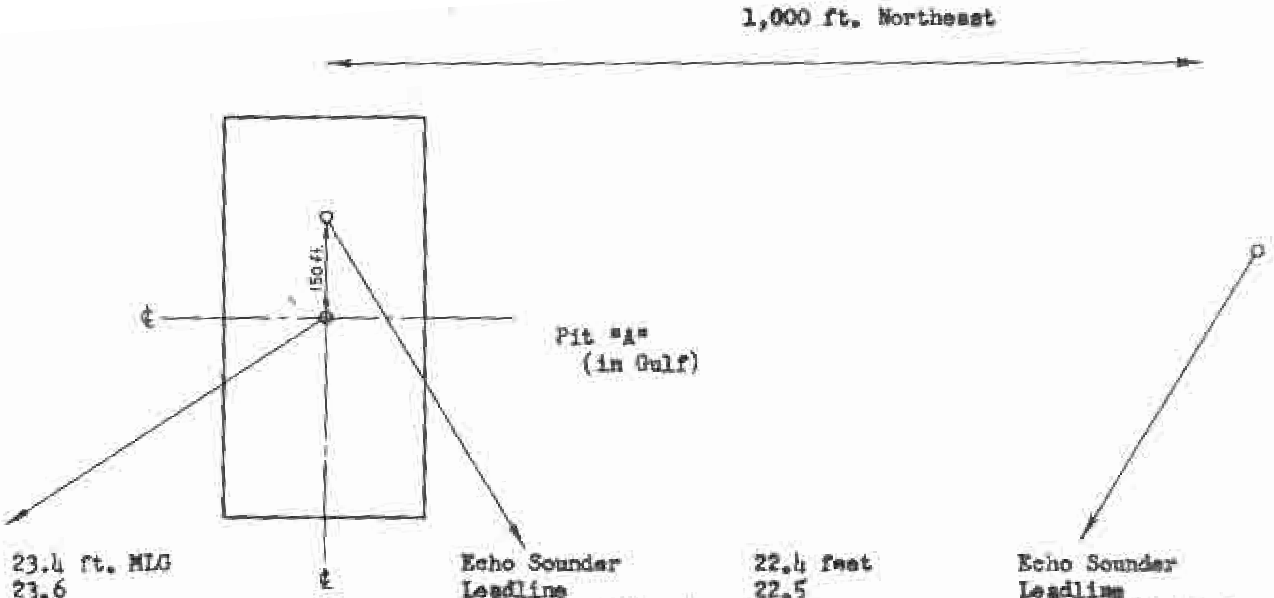


FIGURE D-I TEST PITS IN CHANDELEUR SOUND AREA



Echo Sounder	23.4 ft. MLG
Leadline	23.6
Probe 1020 gpl at	21.7
(med. dia. = 0.16mm at -22')	
1580 gpl at	24.7
1486 " "	27.7
1465 " "	28.7
1605 " "	29.7
Dredged depth	
150' from buoy line	35.0
Original depth,	13.0

Echo Sounder	22.4 feet
Leadline	22.5
Probe 1715 gpl at	23.2
1665 " "	24.7
1475 " "	26.2
1560 " "	27.7
1460 " "	29.0
1770 " "	30.3
Dredged depth	
150' from buoy line,	30.0
Original depth,	13.0

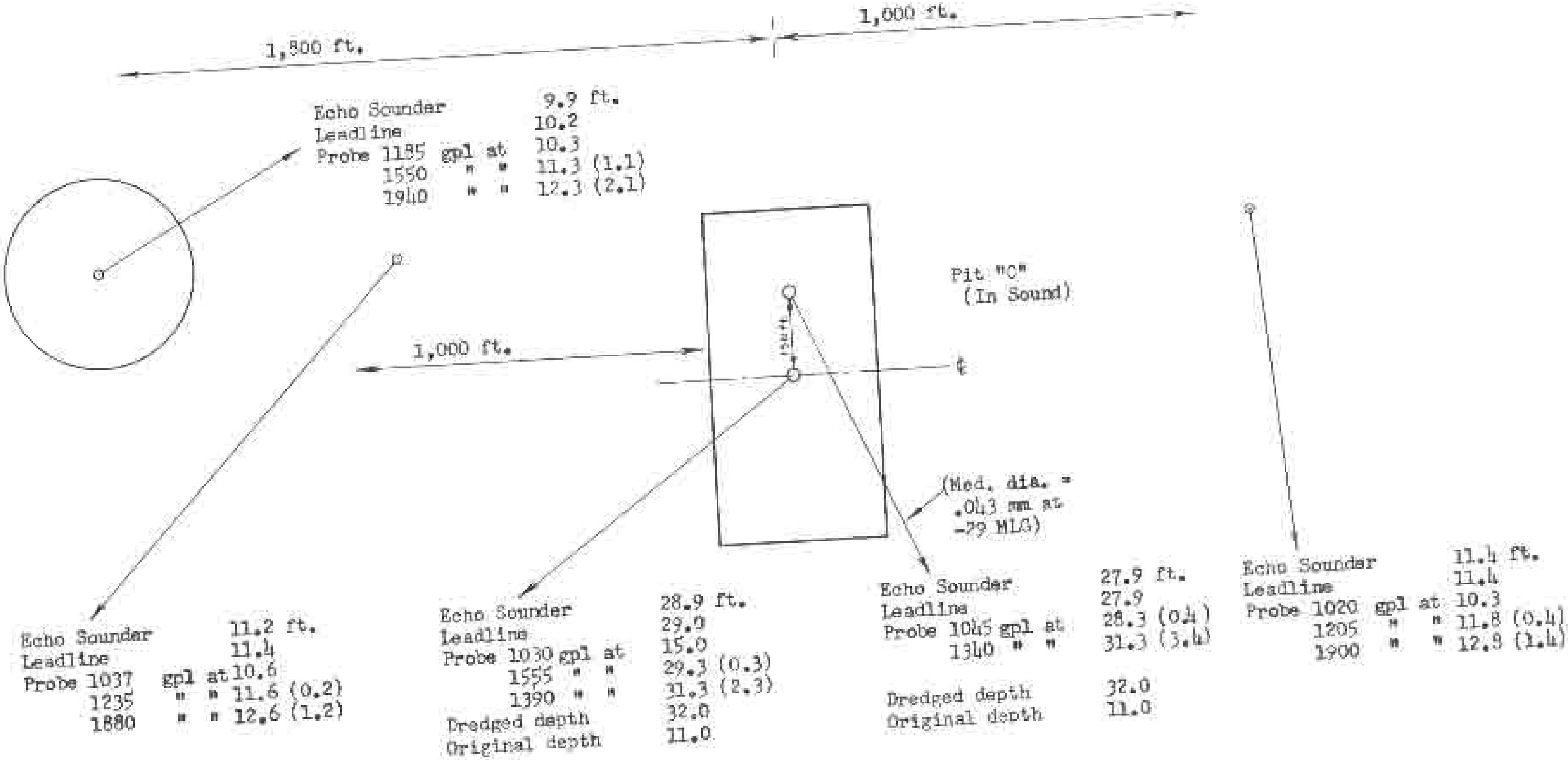
Echo Sounder	13.4 ft.
Leadline	13.6
Probe 1018 gpl at	12.2
1940 " "	14.2

NOTE:

(1) All determinations based on a 5-minute count. Probable error ± 5 gr/liter.
(2) Seawater density = 1026 grams per liter.
(3) Depths are given in feet below mean low gulf (MLG).
(4) Densities are given in grams per liter (thus, 1377).
(5) The probe senses a layer about 1 foot thick centered on the depth given. Probe depths are to mid-point of probe.
(6) Density of saturated fine sand is 1940 grams per liter.

BOTTOM DENSITIES IN GULF
OFF CHANDELEUR SOUND - PIT A
28 January 1959

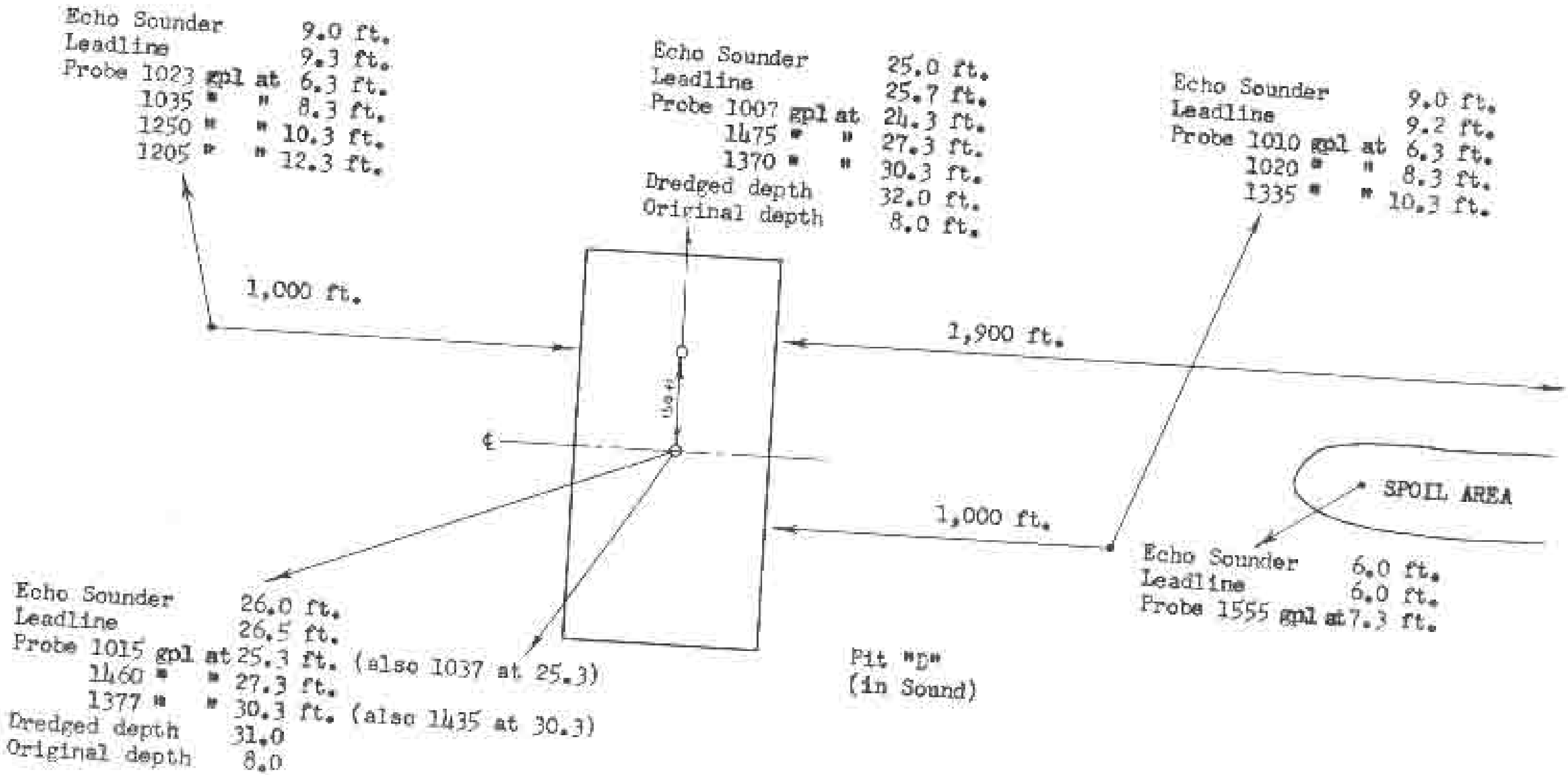
Figure D-2



See Figure D-2 for notes.

BOTTOM DENSITIES IN
CHANDELEUR SOUND-PIT C
29 January 1959

Figure D-3

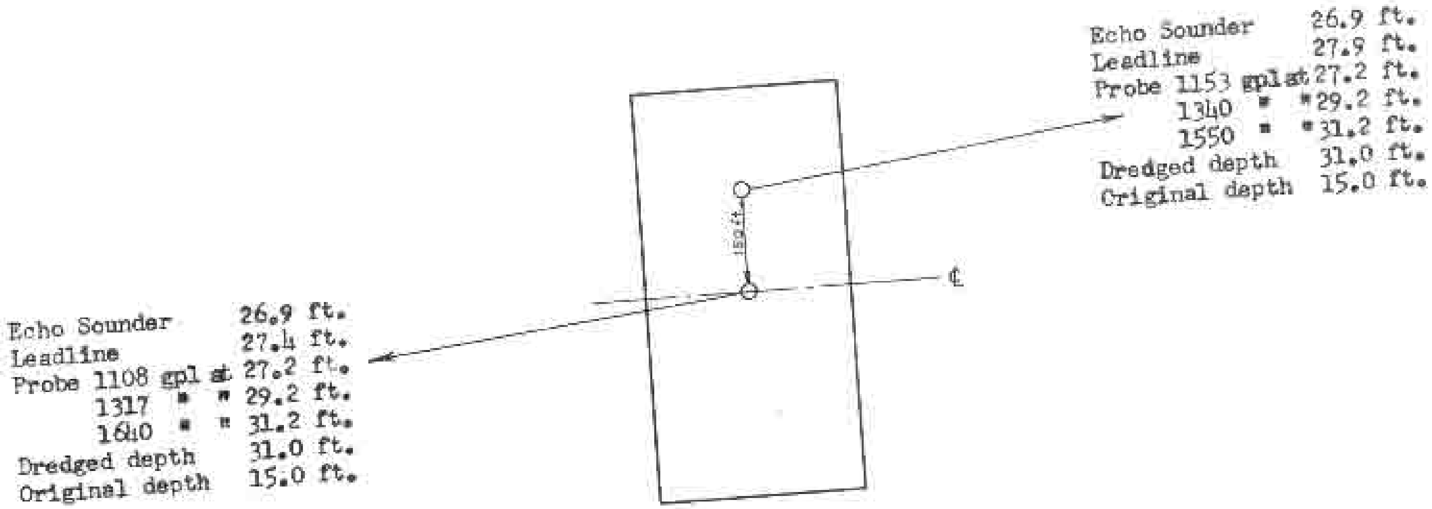


See Figure D-2 for notes.

BOTTOM DENSITIES IN
CHANDELEUR SOUND-PIT D
22 January 1959

Figure D-4

PIT E



BOTTOM DENSITIES IN
CHANDELEUR SOUND-PIT E
23 January 1959

See Figure D-2 for notes.

Figure D-5

TESTS IN SAN FRANCISCO BAY

The following paragraphs are the eight paragraphs constituting the "conclusions" to a report by the San Francisco District covering the District's use of the sediment density probe in San Francisco Bay. The full report is entitled, "Field Use of the Beach Erosion Board In-Place Sediment Density Probe", U. S. Army Engineer District, San Francisco, Corps of Engineers, January 1960.

Conclusions

76. The following is quoted from the 3rd indorsement from the Beach Erosion Board, dated 26 September 1958, to basic letter from the District Engineer, dated 14 August 1958, subject "In-place Density Probe". . . . . "Operation of the instrument does not require specialized personnel. A 30-minute instruction period should be adequate for most personnel at all familiar with instrument operation to become familiar with its operation. The servicing can be accomplished by any good electronic technician. A technician that is familiar with pulse circuits and decade scalers (counters) would, of course, be desirable."

77. The principal difficulty in field work with the probe has nothing to do with the probe itself, but in fixing the position of the survey boat, holding it over station while the impulses are being counted. The advantages of the probe over conventional field sampling and laboratory analysis are quite obvious. Readings may be taken quite rapidly, and conversions to in-place densities may be made on the spot. Of course, this was one of the objectives of the Beach Erosion Board in contracting for the development of the probe. It permits a reading to be taken at the surface of a shoal and then, without withdrawing the probe, pushing the probe further into the material for another reading at a greater depth. This can be continued to the depth of penetration possible with the probe. Thus, using a pipe to handle the probe in a slip in Mare Island Strait, a total of 18 readings through a depth of 18.5 feet were obtained in 31 minutes. Using a cable to handle the probe with a 50-pound weight attached, in the channel of Mare Island Strait, a total of 9 observations through a depth of 5.5 feet were obtained in 12 minutes. And, aboard a hopper dredge, using a handline with the probe and without weight added, 6 observations in each of 7 bins throughout a depth of 27.5 feet were obtained in the average time of 8 minutes; the 42 observations were obtained in one hour and 18 minutes, including the time moving from bin to bin and getting set up.

78. Following the initial outlay, by a District office, the sediment density probe would pay for itself many times over through savings in costs for conventional field and laboratory work.

79. Inasmuch as some hopper dredges are not equipped with draft gage-load indicators, and since some of the dredges experience malfunctioning of the indicators, it is suggested that the density probe be made part of standard equipment aboard the hopper dredges, for load determinations. The probe has the further advantage of showing how the density varies throughout the depth of the bins.

80. The designers of the probe recognize that certain conditions affect its efficiency. They list the most probable causes of inaccuracy as: timing errors; high-voltage variations; counter losses; and scaler incompatibility. They state that variations in temperature between 10°C. and 20°C. have no statistical effect on readings obtained, and that with reasonable care the probe can be used in the field for reproducible, rapid, accurate (better than 1% in 1 minute) silt and sediment density measurements.

81. A comparison of densities of the saline water at six widely-scattered points in the San Francisco Bay system determined with probe and hydrometer, showed a maximum difference of 1.7%.

82. The conclusions in I. L. Kofsky's "Final Report on Development of a Sediment Density Probe" include the following . . . . . "The completed probe is designed to be immersion proof, rust proof, and shock resistant, besides being "optimized" on the basis of the research program. The gamma rays back-scattered by the silt or sediment from a 3-millicurie radium - 226 source, are registered by three halogen-filled Geiger counters and sent back to the scaling circuit by a built-in, transistorized pre-amplifier. The probe is readily portable, and safe to use with only the simplest of radiation safety precautions."

83. Mr. R. B. Krone, Research Engineer of the University of California who checked the calibration of the probe (in a limited container with diameter of 22 inches), developed a curve of responses at various voltage. He concluded . . . . . "The sediment density probe appears to be well designed and should prove very useful to Corps' operations. It is potentially very precise. Its accuracy depends on uniformity of sediment density around it, however, and interpretation of thin horizons should be attempted with caution. As mentioned above, calibration should be made in larger volumes of sediment for the lowest bulk densities."

After reviewing the above quoted San Francisco District report, the Operations Division, Office Chief of Engineers, made the following comment:

"A review of the subject report indicates that a radio-isotope density probe may be useful in both before-dredging surveys and in dredging operations. The problem of developing load meters for hopper dredges is presently under study by the Corps of Engineers Marine Division of the North Atlantic Division Office, as an authorized item in the program for improvement of hopper dredges and hopper dredging. Accordingly, it is suggested that a copy of the San Francisco report and any additional reports or information relating to other field tests of the probe in estuarine waters, be forwarded to the Marine Division for review and comments."

BEACH EROSION BOARD, C.E., U.S. ARMY, WASH., D.C.

DEVELOPMENT AND TESTS OF A RADIOACTIVE SEDIMENT DENSITY PROBE by J. M. Caldwell, September 1960, 29 pp., 4 illus., 9 tables, 5 append. TECH. MEMO. NO. 121

UNCLASSIFIED

1. Instruments & Instrumentation
2. Density gages - Sediment
3. Soils - Density & Moisture

I. Caldwell, J. M.
II. Title

The development, calibration, and laboratory and field testing of an instrument for in-place determination of sediment density is described. The device encased in a submersible probe and utilizing 3 millicuries of radium 226 as a source of radioactivity and 3 halogen-filled Geiger-Muller Counters to detect reflected gamma rays transmits a preamplified signal through a 75-foot cable to a scaler, the signal being correlated to the density of the sediment-fluid mixture. The probe senses the in-place bulk density of sediment surrounding the probe over a sphere of material of about 1-foot radius centered on the probe. Evidence is presented that this device is an accurate and practical tool for use in the field, and that its accuracy is greater and costs less than for other methods presently in use.

BEACH EROSION BOARD, C.E., U.S. ARMY, WASH., D.C.

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